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Development and Demonstration of FRP Composite Fender, Loadbearing, and Sheet Piling Systems

by

Richard Lampo, Thomas Nosker, Doug Barno, John Busel,
Ali Maher, Piyush Dutta, and Robert Odello

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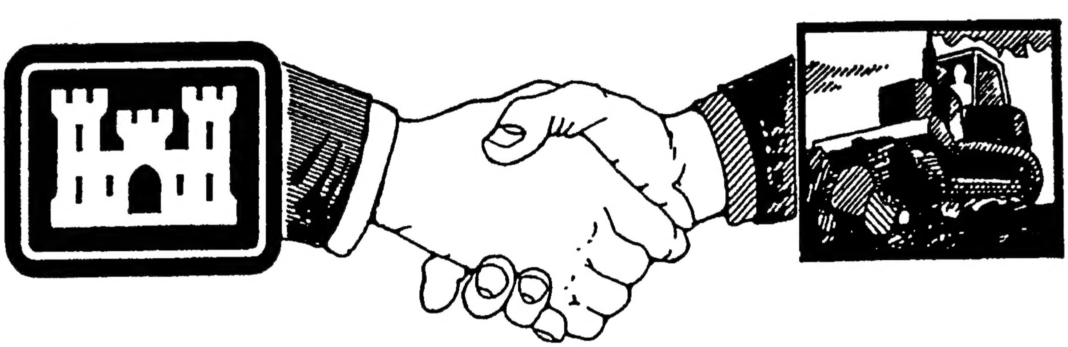

A Corps/Industry Partnership To Advance Construction Productivity and Reduce Costs

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13. ABSTRACT (Maximum 200 words)

Traditional piling systems are inherently unsuited for harsh waterfront environments. Deterioration of wood, concrete, and steel piling systems is estimated to cost the U.S. military and civilian marine and waterfront communities over $1 billion annually. Fiber-reinforced polymer (FRP) composites represent an alternative construction material without many of the performance disadvantages of traditional materials as described above.

A proposal was submitted to develop composite piling systems under the U.S. Army Corps of Engineers' Construction Productivity Advancement Research (CPAR) Program. This CPAR Project developed, tested, and demonstrated high-performance polymer composite fender, load-bearing, and sheet pile (bulkheads) systems for marine/waterfront civil engineering applications. In phase one, mechanical, operating, and physical performance requirements were established. In phase two, laboratory tests were conducted to assess the preliminary designs. Promising designs were further developed and tested. Selected fender piles that met the established requirements, as determined by the laboratory tests, were installed in a field demonstration. Development and adoption of industry consensus specifications and standards for composite piling systems was initiated. The Composites Institute and member manufacturers have promoted and will continue to promote the commercialization of the composite pilings developed under this project.

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Foreword

This research was performed for the Directorate of Research and Development, Headquarters, U.S. Army Corps of Engineers under the Construction Productivity Advancement Research (CPAR) Program; Work Unit LU3, "Development and Demonstration of Polymer Composite Piling and Sheet Pile Systems." The technical monitors were J. Hartman, CECW-ED, D. Chen, CEMP-ET, and T. Wilford, CEMP-CE.

The work was conducted through a Cooperative Research and Development Agreement (CRDA) between the Materials Science and Technologies Division (FL-M) of the Infrastructure Laboratory (FL), U.S. Army Construction Engineering Research Laboratories (USACERL), and the Center for Plastics Recycling Research (later changed to the Plastics and Composites Group, Department of Civil and Environmental Engineering) at Rutgers University, New Brunswick, NJ. Acknowledgement is given to Mal McLaren, M.G. McLaren Consulting Engineers, West Nyack, NY, for his help in developing the Performance Target Goals; Dan Webber, Port Authority of New York and New Jersey, Jersey City, NJ, for his help in getting the demonstration fender piles installed at Port Newark, NJ; and Joel Baron, Lancaster Composite, Columbia, PA, for his guidance and liaison activities between the Composites Institute Market Development Alliance and the CPAR Project Team. A special thanks is also given to the many other individuals (too numerous to list separately) from the Laboratories and to Partner Participants who helped make this project a success. The USACERL principal investigator was Richard G. Lampo, CECER-FL-M, and the Rutgers University principal investigator was Dr. Thomas J. Nosker. Ilker Adiguzel is Acting Chief, CECER-FL-M, and Dr. Alan Moore is the responsible Technical Director, CECER-FL. The USACERL technical editor was William J. Wolfe, Technical Resources.

COL James A. Walter is Commander and Dr. Michael J. O'Connor is Director of USACERL.

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1 Introduction

Background

Traditional piling systems are inherently unsuited for harsh waterfront environments. Pressure-treated timber pilings are subject to attack by marine organisms (Figure 1) and pose disposal problems when being replaced. Steel-reinforced concrete piles can fail due to chloride attack on the reinforcing elements (Figure 2) and freeze/thaw degradation of the concrete. The problems of corrosion on steel sheet piling are well known. Overall, the authors estimate that deterioration of wood, concrete, and steel piling systems costs the U.S. military and civilian marine and waterfront communities on the order of $1 billion annually.

Such traditional practices as using pressure-treated timbers, or sandblasting and painting steel with coatings containing solvents and/or heavy-metals are potentially harmful to the environment. For this reason, these practices are increasingly regulated. Fiber-reinforced polymer (FRP) composites represent an alternative construction material without many of the performance disadvantages of traditional materials as described above. Properly designed and manufactured FRP composite piling systems promise to be superior to traditional materials in marine operating environments. FRP composites have been successfully used in load-bearing structures for the chemical processing, oil and gas, and water/wastewater industries over the past 30 to 40 years. Still, the design and long-term performance of FRP composite products in civil engineering structures must be tested and demonstrated before the U.S. construction industry will accept the material for such applications. Once this technology has been successfully tested, its transfer to widespread use in marine/waterfront civil engineering structures, U.S. ports, harbors, and waterways operators is expected to save millions of dollars annually.

Figure 1. Wood pile attacked by marine borers.

Recognizing the needs, a proposal was submitted by the Center for Plastics Recycling Research (CPRR), Rutgers University* to develop composite piling systems under the U.S. Army Corps of Engineers' Construction Productivity Advancement Research (CPAR) Program. (Appendix A gives further information on the CPAR Program.) The project was approved for execution starting in April 1994. A CPAR Cooperative Research and Development Agreement (CPAR-CRDA) was then developed and signed. The industry/academic partner on this project was Rutgers University, Department of Civil and Environmental Engineering (C&EE)/the Polymers and Composites Group (P&CG), New Brunswick, NJ, and the Laboratory Partner on this project is the U.S. Army Construction Engineering Research Laboratories (USACERL), Champaign, IL.

* Later changed to the Plastics and Composites Group, Department of Civil and Environmental Engineering, Rutgers University.

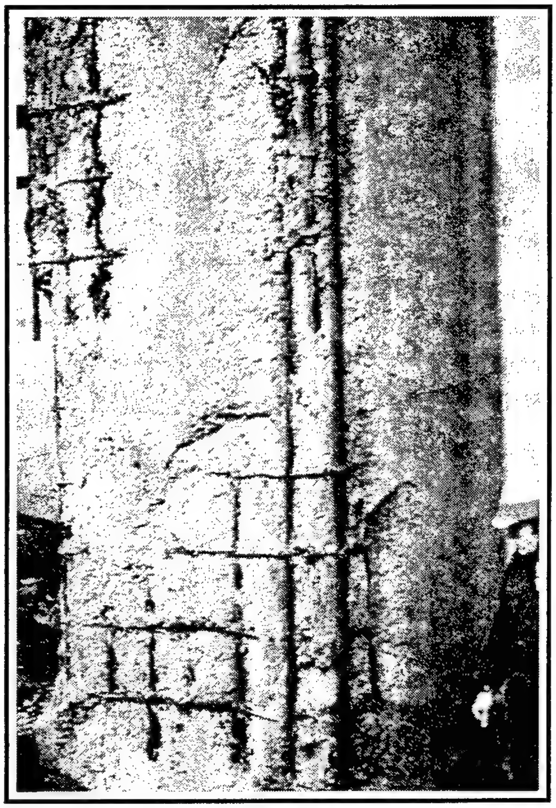

Figure 2. Concrete pile failing due to corrosion of steel reinforcement.

The Composites Institute (CI), Harrison, NY, (representing hundreds of member manufacturers and raw material suppliers to the composite industry) also entered into this Agreement as a partner participant under Rutgers providing significant in-kind support of materials and products for testing and field demonstrations. Another vital partner participant identified in the CPAR-CRDA is the Port Authority of New York and New Jersey (PA NY/NJ), Jersey City, NJ. Other Laboratory participants include: the U.S. Naval Facilities Engineering Service Center (NFESC), Port Hueneme, CA, the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), Hanover, NH, and the U.S. Army Waterways Experiment Station (WES), Vicksburg, MS. An Advisory Board consisting of representatives of the leading marine/waterfront organizations were recruited to provide practitioner feedback to the project team: the American Association of Ports Authorities (AAPA), the American Society of Civil Engineers (ASCE), the Permanent International Association of Navigation Congresses (PIANC), etc.; ports authorities including the Port of Boston/Massachusetts Port Authority, Port of New Orleans, Port of Tampa, World Port LA, and the Port of Seattle. In addition, *Pile Buck*, the piling industry's leading magazine, agreed to serve on the Advisory Board to provide contractor perspective and piling industry information. The following

manufacturers, as part of a Market Development Alliance under the Composites Institute, were also participants:

- Creative Pultrusions, Inc., Pleasantville Industrial Park, Alum Park, PA 15521, tel: (814) 839-4186
- Hardcore DuPont Composites, LLC, 42 Lukens Dr., New Castle, DE 19720, tel: (302) 427-9250
- International Grating, Inc., 7625 Parkhurst, Houston, TX 77028, tel: (713) 633-8614
- Lancaster Composite, Inc., 1000 Houston St., Columbia, PA 17512-0247, tel: (717) 684-4440
- Seaward International, Inc., 3470 Martinsburg Pike, Clearbrook, VA 22624-0098, tel: (540) 667-5191
- Shakespeare Company, Rte. 31, Newberry, SC 29108, tel: (803) 276-5504
- Specialty Plastics, Inc., 15915 Perkins Road, Baton Rouge, LA 70879, tel: (504) 752-2705
- Trimax of Long Island, 2076 Fifth Ave., Ronkonkoma, NY 11779, tel: (516) 471-7777.

Project Objective

The objective of this CPAR Project was to develop, test, and demonstrate high-performance polymer composite fender, load-bearing, and sheet pile (bulkheads) systems for marine/waterfront civil engineering applications. Material standards, specifications, and design protocol will be developed for each type piling system.

Approach

Project activities followed the project execution plan as outlined in the original project proposal and signed CPAR-CRDA. In phase one, mechanical, operating, and physical performance requirements were established. Installation requirements and cost targets were also considered. With an understanding of the requirements and an assessment of how the traditional materials perform, preliminary product designs were developed for each of the piling types. In phase two, laboratory tests were conducted to assess the preliminary designs. Promising designs were further developed and tested. Selected fender piles that

met the established requirements, as determined by the laboratory tests, were installed in a field demonstration. Development and adoption of industry consensus specifications and standards for composite piling systems was initiated. The Composites Institute and member manufacturers have and will continue to promote the commercialization of the composite pilings developed under this project.

Scope

Nontraditional, steel-cored plastic piles (made from recycled waste plastics) were already on the market and in some limited applications prior to the initiation of this CPAR Piling project. In fact, failures of these type piles in fendering applications at PA NY/NJ facilities stimulated the initial ideas on how to possibly design a superior pile using fiber-reinforced polymer composites. Manufacturers who were already making FRP composite piling products and several other manufacturers who wished to start making such products were then identified. As with the steel-cored plastic piles, the existing composite piling products had not yet achieved any significant market share when competing against the traditional materials. By virtue of the manufacturers that made up this project Team, and their different needs, this CPAR piling project attempted: (1) to help those manufacturers already producing a performance-acceptable piling system to increase market acceptance and to provide suggested design/performance enhancements to their products, and (2) to help those manufacturers just getting started in this application area to develop new products to compete with the traditional piling systems and other nontraditional systems. (Note that, by virtue of the Composites Institute's commitment to this project and accepted project definition, only those piling systems or designs that made significant use of fiber reinforced polymer composites were considered under this project.)

The project title and objective refer to "piling systems." In an exact sense, a piling system would include items such as walers, camels, and other components. While keeping in mind that individual piles will become a part of a system in actual installations, the project focused specifically on the development, test, and demonstration of various piles as separate components to a "piling system."

Metric Conversion Factors

The following metric conversion factors are provided for standard units of measure used throughout this report:

1 in.	=	25.4 mm
1 ft	=	0.305 m
lbf (lb force)	=	4.448 joules/m (Newtons, or N)
1 kip	=	4.448 kN
1 psi	=	6.895 kPa
1 lb-sq in.	=	0.029 N-m^2
°F	=	(°C x 1.8) + 32

2 FRP Composites as Construction Materials

Definition of Composites

The generic definition of composites is a combination of two or more materials (constituents) differing in form or composition on a macroscale, yet the constituents retain their identities (i.e., they do not dissolve or merge into each other) and act in concert to perform a particular function. For the purposes of this report, the term "fiber-reinforced polymer" (FRP) is used to identify any form of fiber-reinforced polymer composite material. The definition of an FRP composite used in structural/civil applications is, "A matrix of polymeric material that is reinforced by fibers or other reinforcing material" (Composites Institute 1995a). This includes thermosets, thermoplastics, or elastomers that are reinforced by fibers or other material with an aspect ratio of length to width sufficient to produce a reinforcing function in one or more directions. In this report, the term "composites" is used specifically to refer to FRP composites.

Classical composites comprise a polymer matrix (polyester, vinylester, epoxy, phenolic, thermoplastic, etc.) which is reinforced with fibers (glass, carbon, aramid, etc.), in much the same way as concrete is reinforced with steel. Other terminology for composites include fiber-reinforced plastic, glass fiber reinforced plastic (GFRP), carbon fiber-reinforced plastic (CFRP), reinforced plastics (RP), and others. The fabrication of composites is just as important as the materials. Depending on the application, performance requirements, size, production volume, production rate, cost, and others, composites can be produced by over 10 different fabrication methods.

Composites have been used for more than 50 years. These materials have demonstrated to be extremely effective in high-performance applications where traditional materials have failed, especially in aggressive environments. Currently, FRP composites are tracked in eight different market segments. These end-use markets are: transportation, construction, marine, business equipment, corrosion-resistant equipment, electrical, consumer, and aircraft/

aerospace. Composites are used mostly in transportation, followed by construction.

According to the Composites Institute, estimated 1998 shipments of composites are expected to reach nearly 3.5 billion pounds. Composites account for approximately 5 percent of the annual output of the U.S. plastics industry (Composites Institute 1995a). The use of FRP composites in specific infrastructure applications has been shown to be technically superior, however, commercial deliveries in this market are relatively small compared to the current markets, and are therefore just starting to be tracked. The Composites Institute Market Development Alliance believes that the infrastructure market is potentially huge and is dependent on the proper selection of materials for the right applications.

Composite materials offer many advantages over conventional materials. Properly designed and fabricated composite products provide one or more of the following benefits (Composites Institute 1995b; Corps of Engineers 1997):

- high strength
- oriented strength
- light weight
- high strength-to-weight ratio
- corrosion resistance
- parts consolidation
- design flexibility
- low maintenance
- reduced life-cycle costs
- dimensional stability
- high dielectric strength / non-magnetic properties
- nil environmental toxicity
- ability to incorporate post-consumer and post-industrial materials
- recyclability.

The above-identified property benefits can provide important property advantages when comparing piling products made from polymer composites to traditional materials such as wood, concrete, and steel.

Composite Materials for Pilings

Polymeric resin materials used to fabricate composite piling products involve two different resin types: thermoplastic and thermoset. Thermoplastics are comprised of long hydrocarbon polymer chains that are not chemically bonded to each other. Thermoplastic materials soften when heated and harden upon cooling, hence the joining of the terms "thermo" (heat) and "plastic" (formable). They can be remolded into a different shape through the use of heat and force. Assuming no thermal degradation or oxidation during multiple heating and cooling cycles, this process can be repeated indefinitely. Common examples of thermoplastics are polyethylene (PE), polypropylene (PP), polystyrene (PS), and polyvinyl chloride (PVC).

Thermosetting resins are normally liquids, or in a few special cases, solids with low melting point temperatures (Composites Institute 1995b). These resins are chemically reacted to form bonds between the hydrocarbon chains which, in turn, changes the resin from a liquid to a solid. Generally, a thermosetting reaction process can not be reversed. Also, the application of heat cannot generally be used to reshape the item as in a thermoplastic. Polyesters, vinyl esters, and epoxies are common examples of commercial-grade thermosetting resin systems.

While a variety of fiber types can be used for reinforcements in FRP composite materials, glass fibers would be the most common choice for composite pilings. Glass fibers offer good strength and stiffness properties at a reasonable cost. In fact, glass-fiber reinforced polyester composites make up approximately 85 percent of the total production of FRPs.

The composite piling products developed and tested under this CPAR project involved both reinforced thermoplastic and thermoset resins. Glass fibers were used in a variety of forms (i.e., continuous fibers or rovings, chopped fibers, and cloths or mats) as described in further detail in the following Chapter. Additional information about FRP composites technologies can be found in Composites Institute (1995) and Corps of Engineers (1997).

Barriers to Using Composites in Construction

FRP structural composite technology holds great promise for the U.S. civil engineering infrastructure and construction industry (including the use of composite pilings for marine and waterfront applications). However, several barriers must be overcome for FRPs to be accepted on a widespread basis. These barriers fall into two categories: (1) technical and (2) institutional. Technical barriers include engineering, scientific, manufacturing, or operational problems that prevent the acceptance of new technologies into existing markets. Economic necessity requires FRP structural composite products to be: (1) cost-competitive or less expensive on a first-cost (installed) basis, (2) provide significant life-cycle cost advantages, and (3) be constructed (or at least for the first several product generations) using current standard industry practices. Specific technical barriers regarding composite piling products and systems for marine/waterfront applications are as follows:

- Lack of widely-accepted end-use performance standards
- Characterization of mechanical and physical properties
- Design calculations via credible third-party endorsed design practices
- Cost (first cost versus life-cycle, etc.)
- Constructability (component versus system)
- Proof of durability (properties retention, fire performance, etc.)
- Test methods (mechanical property verification as well as long-term and accelerated).

Institutional barriers relate to the conservative nature of the construction industry, the fear of liability, and the lack of 50 years of in-place structural performance data in construction related applications and minimum incentives for the application of innovative new technology. Also, until recently, there has been little interaction between the composites industry and the construction industry. Specifically, the communication links or technology transfer mechanisms in place between the composites industry, civil engineers, and specifiers are relatively new and not widely known. The institutional barriers to the use of FRP composites in structural civil engineering applications are summarized in the following list:

- Low U.S. civil engineering R&D investment
- Little or no "industrial" R&D

- Fragmented and decentralized civil engineering industry influence factors
- Liability and litigation
- Codes and specifications (complex, decentralized, duplicating, and overlapping)
- Lack of practitioner education
- Contract delivery system (public sector)
- Industry-specific issues such as multiple pre-competitive technologies, reluctance to share proprietary technologies, and limited U.S. based technologies
- Difficulty in securing demonstration sites.

The work performed under this CPAR project represents a concerted effort by the participants (government, academia, and industry) to recognize the above mentioned issues and barriers and to begin to address the needs relative to the manufacture, specification, and use of composite pilings in marine/waterfront applications. Additional information regarding the use of FRP composites in construction and civil engineering applications can be found in a number of references including Bassett (1998) and Composites Institute (1995c).

3 Development of Designs

Performance Target Goals

Existing design guidance for piling and sheet pile systems was compiled, circulated, and reviewed. Most of this information came from the Navy and Corps of Engineers. (A listing of these documents can be found in the References section at the end of this report.) A survey of existing piling systems made from nontraditional materials was conducted by Rutgers University and the Composites Institute (CI). Information on system needs was also collected from various end user participants. These users included Corps of Engineer Districts (especially Chicago, Memphis, and New Orleans), the Navy, the Port Authority of NY/NJ, New York State Department of Transportation (DOT), and the City of New York, among others. Performance target goals for each type composite piling system were established by the Project Team using the survey results of existing systems, user input relative to system needs and performance expectations, and currently available design guidance for piling systems. Some select, critical performance goals follow. (The complete Performance Target Goals for each type piling can be found in Attachment C of the Design Competition Package that is presented in Appendix B of this report. The Design Competition is further described below.)

Fender Piles

- Cross-section shall not exceed 13x13 in. wide
- Shall not exhibit brittle behavior when subjected to a lateral load at –40 °F at a strain rate of 100 percent/minute
- Minimum flexural stiffness (EI) of 6.0×10^8 lb-sq in.

Loadbearing Piles

- Cross-section shall not exceed 16x16 in. wide
- Minimum load capacity of 704 kips.*

Sheet Piling

- EI of 2.48 x 10^5 kip-sq in./ft, for light-duty sheet piling, to
- EI of 5.5 x 10^6 kip-sq in./ft, for heavy-duty sheet piling.

Each of these composite pilings must be capable of being installed using conventional equipment. At minimum, each of these composite pilings shall demonstrate cost savings over the life cycle as compared to traditionally used noncomposite piling material.

Design Competition

After several reiterations, the Performance Target Goals were considered ready to put forward to the manufacturers to design against. In September 1995, CI's Market Development Alliance announced a Design/Fabrication Competition referencing these Performance Target Goals.

As a result of the design competition, several innovative designs were submitted from CI member manufacturers and design firms. Five different fender piling designs/products, six different loadbearing pile designs/products, and three different sheet pile designs/products were selected for laboratory testing. Table 1 lists the participating manufacturers and the products developed and evaluated for each system type. Figure 3 shows piling cross-sections corresponding to the descriptions in Table 1.

*This value was not explicitely stated in the Performance Target Goals. Rather, it was calculated using the required axial compressive strength of 3,500 psi and assuming a swept area of a 16-in. diameter round wood pile; 3,500 lb/sq in. x 201 sq in. = 704 kips.

Table 1. Participating manufacturers and product systems.

Manufacturer	Fender	Bearing	Sheet
Creative Pultrusions, Inc.	Glass fiber reinforced thermoset polymer matrix, tic-tac-toe profile with (HDPE)* cover	Glass fiber reinforced thermoset polymer matrix, tic-tac-toe profile	Glass fiber reinforced thermoset polymer matrix, Z-shaped profile
Hardcore Dupont Composites, LLC	Concrete filled and unfilled, glass fiber reinforced thermoset polymer matrix tubes	Concrete filled, glass fiber reinforced thermoset polymer matrix tube	—
International Grating, Inc.	—	—	Glass fiber reinforced thermoset polymer matrix composite, corrugated profile
Lancaster Composite, Inc.	Concrete filled, filament wound, glass fiber reinforced thermoset polymer matrix tube	Concrete filled, filament wound, glass fiber reinforced thermoset polymer matrix tube	—
Seaward International, Inc.	HDPE reinforced with glass fiber reinforced polymer composite rebars	HDPE reinforced with glass fiber reinforced polymer composite rebars	—
Shakespeare Company	—	Unfilled, filament wound, glass fiber reinforced polymer matrix tube	—
Specialty Plastics, Inc.	—	Unfilled, filament wound, glass fiber reinforced polymer matrix tube	—
Trimax of Long Island, Inc.	HDPE reinforced with chopped glass fibers	—	HDPE reinforced with chopped glass fibers, tongue and groove profile
*High Density Polyethylene			

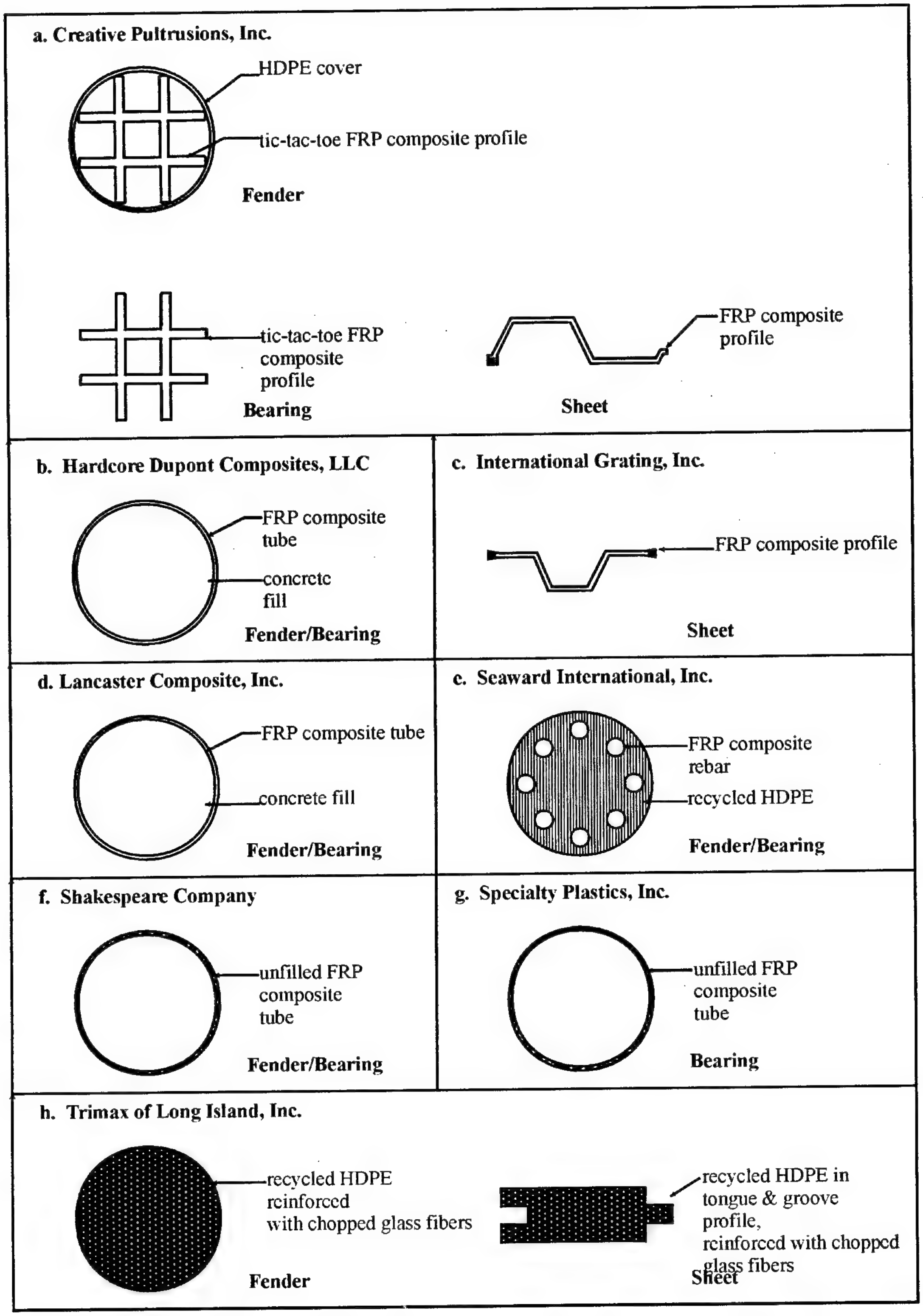

Figure 3. Cross-sectional profiles of candidate piling products (not to scale).

4 Laboratory Tests

Table 2 lists the laboratory testing program for each piling type. (The testing program for each piling type was outlined in Attachment D in the Design/Fabrication Competition given in Appendix B to this report.) During a project meeting on 29 November 1995, the Design Competition Judging Team (made up of the Government and Academic personnel within the Project) and the manufacturers decided to conduct a single "screening" test on each candidate product. Using this approach, results from the test that were considered the most difficult to meet or the most critical for satisfactory performance would allow the manufacturer an opportunity to revise or improve its product (if the results of the screening test were not up to expectations or within the established Performance Target Goals) before additional tests were conducted. The following tests were selected for the screening tests: Fender Piles — cold radial compression; Bearing and Sheet Piles — flexural stiffness. After reviewing the results of the "screening tests," the remaining tests were performed, as warranted. The laboratory tests performed as part of this Project are described below relative to each pile type (not by the sequence in which the tests were actually performed).

Fender Pile Testing

When considering alternative piling materials, it is logical to use wood as a basis of comparison because of its widespread use and known performance in marine/waterfront applications. However, wood was originally selected because it is naturally abundant and easy to machine, and because its performance has been demonstrated empirically over time.

Table 2. Summary of laboratory tests.

Type	Tests
Fender	Flexural test to determine EI. Cold bending (flexural) test to evaluate fracture potential in cold conditions. Cold radial compression test to evaluate behavior in a crushing mode.
Bearing	Flexural test to determine EI (for buckling). Compression to determine compressive strength and load capacity. Creep measurement.
Sheet	Flexural test to determine EI and bending strength. Determine potential for built-up structures (to increase moment of inertia).

Note that optimum material properties for a fender piling have probably not been established by the developed Performance Target Goals since wood was used as the basis for most of these properties. (Deviations from the properties of wood do not necessarily imply that a material will not perform adequately in service.) In this CPAR project, it was determined through contact with many types of docking installations that fender pilings undergo, by design, a wide range of loading conditions.

Two main categories of loading situations were found in this study. The first loading situation is those applications that use the piling predominantly in a bending mode to absorb berthing energy. This is typically done with a number of extra components to the fendering system, such as camels (floating fenders) that act between the fender piling itself and the berthing craft to distribute load to several fender piles. Newer installations generally use this type of design. The second loading situation places the fender piling directly in contact with the berthing craft, and under certain tide or water level conditions, in compression between the craft and the concrete pier surface. Some older installations use this type of design. This is considered a much more severe service type of installation, as most of the energy of a berthing craft must be absorbed in a radial pinch (compression) at a very high strain rate. By contrast, the first loading situation applies a bending strain at several orders of magnitude lower strain rate for an equivalent speed berthing craft.

Key to the issue of economics for installing any alternate type of material in civil structures is whether the alternate materials will be cost-effective over the lifetime of the installation. It is therefore best to consider substitution first in those installations where traditional materials have the lowest longevity. Fender pilings fall into this category, especially in older installations where the pile is subjected to radial crushing forces as described above. Based on the Research Team's understanding of the types of loading situations that fender pilings would be subject to, coupled with the well-documented time and temperature dependence of polymeric systems that make up the binders for the composite materials from which the pilings would be fabricated, several laboratory tests were recommended for studies prior to field trials. These types of tests were:

1. *Radial Compression, at –40 °F (-40 °C), 100 %/minute Strain Rate.* This experiment is meant to evaluate usefulness in an installation where a boat impinges on a pile backed by a concrete slab. This test is used to determine how much energy is absorbed without causing permanent damage to the pile (i.e., the more energy absorbed, the greater the berthing energy that can be

absorbed by each pile). The cold radial compression test was originally developed based on the conditions and geometries present at site conditions typical at Ports Elizabeth and Newark, NJ. The test design took into account the performance of wood fender piling and experience from previously installed plastic fender piles that failed in service at those locations. Meeting this cold pinch condition is not considered critical to the function of the fender pile where the pile has the ability to flex to absorb the berthing energy. For these conditions, flexural testing (at room and low temperatures) is considered most important.

2. *Flexural Test to Determine EI.* This experiment is meant to evaluate usefulness in an installation where kinetic energy from a boat is absorbed by a piling in elastic bending. Testing was performed on long (32-ft) and short (10-ft) spans to estimate the error associated with using the less expensive (shorter span) testing results to correlate properties. This was necessary to determine whether testing on spans shorter than 16:1 length-to-depth (L:D) ratios, which were necessary for sub-ambient testing, would yield meaningful results.

3. *Cold Flexural Test*. This experiment is meant to evaluate whether a piling in a system designed for bending will be subject to fracture at small strains at low temperatures. A piling that is excessively brittle at low temperatures is undesirable, and would not be able to absorb significant berthing energy. Because of size restrictions in the controlled low-temperature (–20 °F) testing room, the ASTM recommended 16:1 L:D ratio could not be met, and shorter (10-ft) spans must be tested.

In practically, all of the mechanical property testing of fender pilings, excellent correlation (within 10 percent) was found when multiple samples were tested in any given experiment. As such, the associated tables indicate average values. Where there is an exception, it is noted with multiple results.

Cold Radial Compression "Screening" Testing of Fender Piles

Radial Compression testing was done at Rutgers University, at a temperature of –40 °F (Figure 4). Samples were 4 in. thick, and taken from the cross-sections supplied by the manufacturers. All samples were conditioned at –40 °F for 24 hours prior to testing.

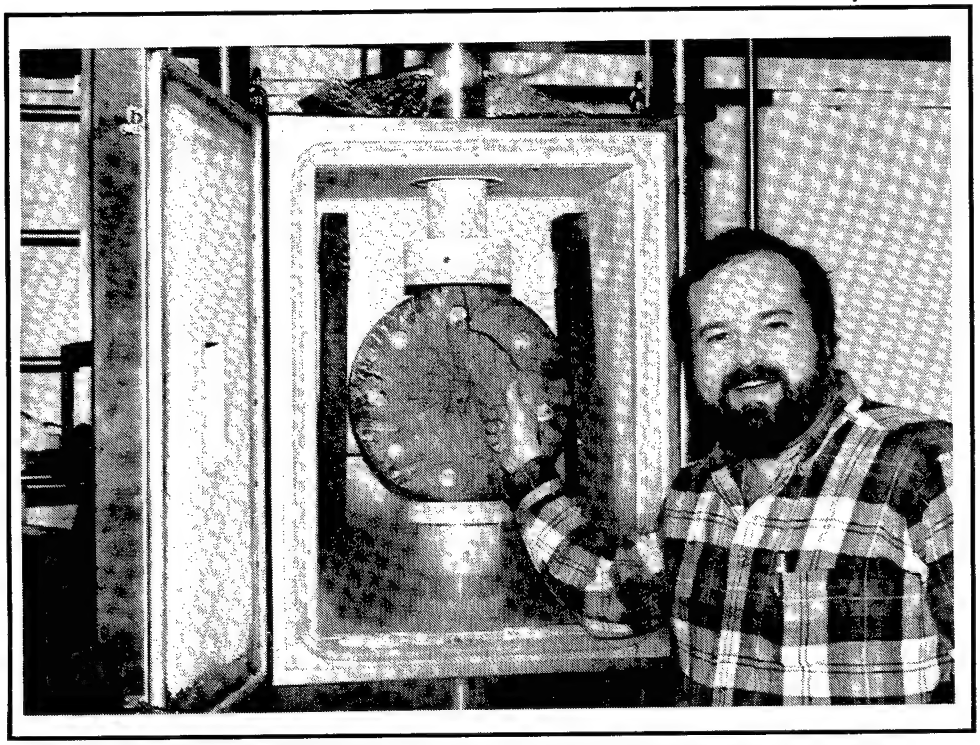

Figure 4. Test apparatus used to conduct radial compression of fender piling sections.

Three manufacturers (Creative Pultrusions, Seaward International, and Hardcore DuPont) supplied round pilings with a nominal 13-in. diameter. Two manufacturers (Lancaster Composite and Trimax) supplied samples that were round, with diameters smaller than 13 in. The Lancaster Composite piling specimens had a diameter of 4 in., while the Trimax pilings had a diameter of 10 in. In these cases, the results were multiplied by a ratio factor relative to the specimen diameter and 13 in. in order to approximate the performance at a 13-in. diameter.* In each case, the samples were tested in the full cross-section supplied at a radial compression strain rate equating to 100 percent per minute. (That is, a cross-head movement of 13 in. per minute for a 13-in. diameter pile, proportionately reduced for smaller diameter specimens.) Each sample was tested to failure, or past 20 percent strain, whichever came first. Up to four samples were tested of each type, if that number of samples was provided for testing. The three types of Hardcore DuPont pilings (listed as Types 1, 2, and 3) supplied for this test corresponded to 3, 5, and 7 layers of fiberglass matting

* While recognizing that errors may be introduced with such scaling operations, the Project Team could only work with the samples provided. The relative results were not, however, inconsistent with what was predicted based on material compositions and geometries.

making up the tubes, respectively. In all three cases, the tubes provided for this experiment were supplied hollow. The Creative Pultrusions pilings consisted of two types, one with a plastic foam core, and one with polyethylene boards in the core (Figure 5). Both of these pilings had a geometry that was positioned parallel and perpendicular to the compression platens in one test, and skewed at a 45-degree angle to the platens in the other. New, chemically treated wood pile specimens with a diameter of 13 in. were also tested for comparison (Figure 6).

Table 3 lists the average results for the cold radial compression tests. Figures 7 to 9, respectively, show the initial slope of the force-displacement (F/D) curve (stiffness indicator), the force at failure, and the energy absorbed. The overall shapes of the F/D curves differed significantly from one type pile to another. After an initial linear slope, the curves sometimes had an up-curvature or down-curvature. The energy absorbed, the primary value of interest, was determined by measuring the area under the F/D curve. This data makes it apparent that some of the composite pilings can absorb significantly more energy than wood pilings under low temperature radial compression without failure. The Research Team recognized that this fact represents a significant advantage for composite pilings, assuming installation issues are minor. Also note that the wood samples tested were much stiffer (initial slope of the curve) than the composite pilings tested in this experiment. The less-stiff composite piles could pose a problem if easily damageable structures lie a short distance beyond the most outward facing surface of the piling. Also, the force at failure for wood is higher than that of the composite pilings. These facts did not overly concern the team because the most critical engineering parameter measured here is the elastic energy absorbable by the pile. It is hoped that this quantity, normalized over many piles, will stop a moving ship.

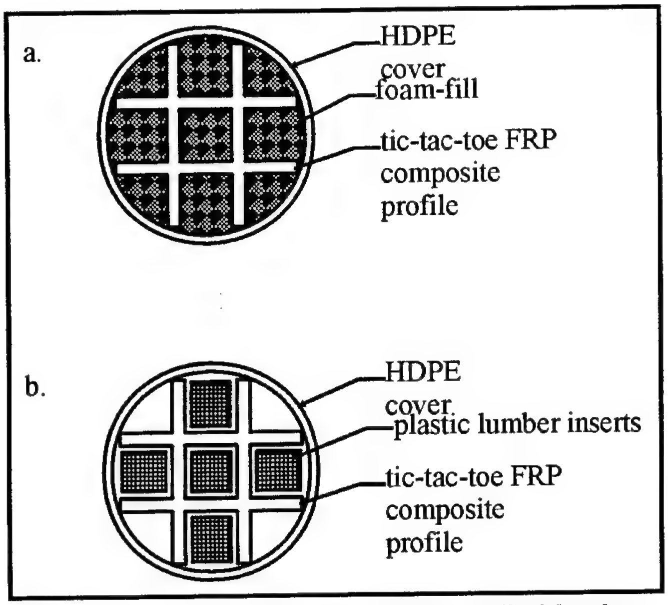

Figure 5. Cross-sectional profiles of filled fender piles by Creative Pultrusions (not to scale).

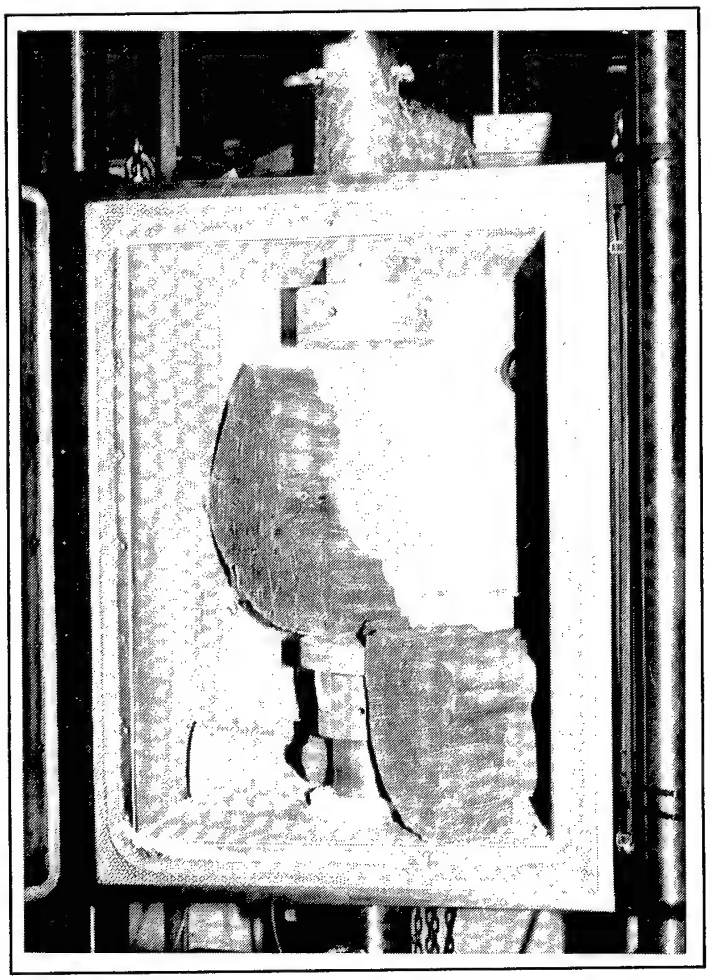

Figure 6. Failure mode of wood pile tested in radial compression at -40 °F.

Table 3. Summary of average results for cold radial compression tests on fender pile specimens.

Company	# Tested	Initial Slope of F/D Curve (lb/in)	Force at Failure (lb)	Displacement at Failure (in)	Energy Absorbed (ft-lb)	Indication of Failure*
Lancaster Composite**	1	120,718	9,435	0.29	23	Yes
Creative Pultrusions Type 1***	1	6,513	20,750	1.34	595	Yes
Creative Pultrusions Type 1 Skewed†	2	8,222	975	0.32	15.5	Yes
Creative Pultrusions Type 2	2	7,850	50,000+	1.10	590+	No
Creative Pultrusions Type 2 Skewed	2	4,806	7,875	1.40	311	Yes
Trimax**	3	346,710	22,728	0.28	44	Yes
Seaward	4	317,151	18,237	0.18	26	Yes
Hardcore Type 1	3	584	492	—	12	No
Hardcore Type 2	4	1,727	1,150	—	29	1-Yes 3-No
Hardcore Type 3	4	4,871	2,875	2.23	71	Yes
Wood, new chemically treated	3	1,503,125	80,438	0.39	42	Yes

* Failure was determined by visual or audible indication of specimen fracture.
** Results scaled up to approximate performance of 13-in. diameter pile.
*** Foam-filled.
†Specimen rotated so tic-tac-toe profile was at a 45-degree angle to the machine loading platens.

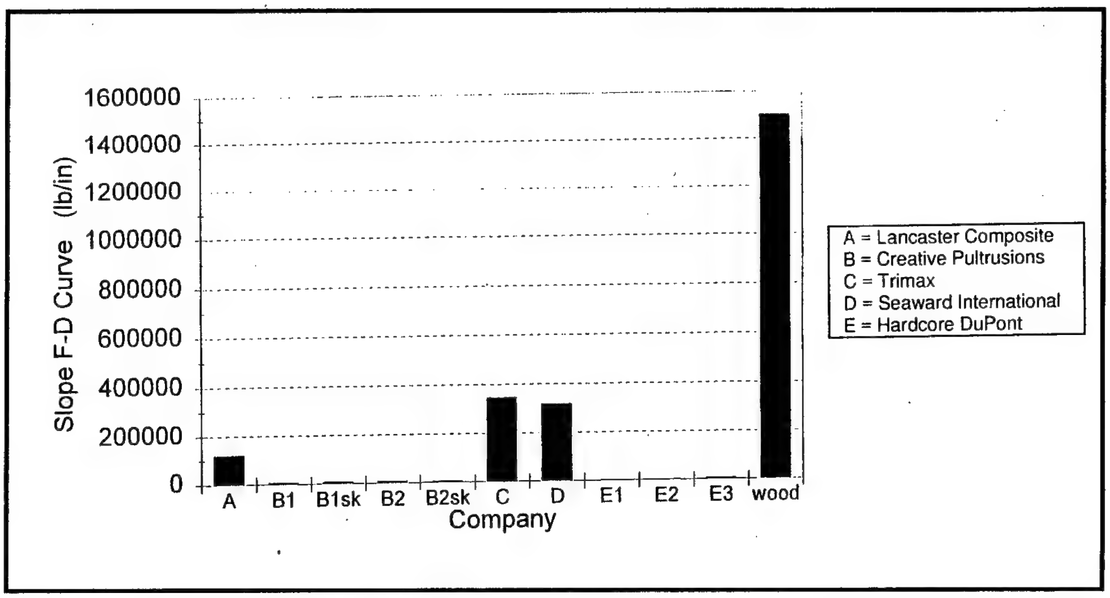

Figure 7. Initial stiffness (slope of force-displacement curve) of pile specimens tested in radial compression at -40 °F.

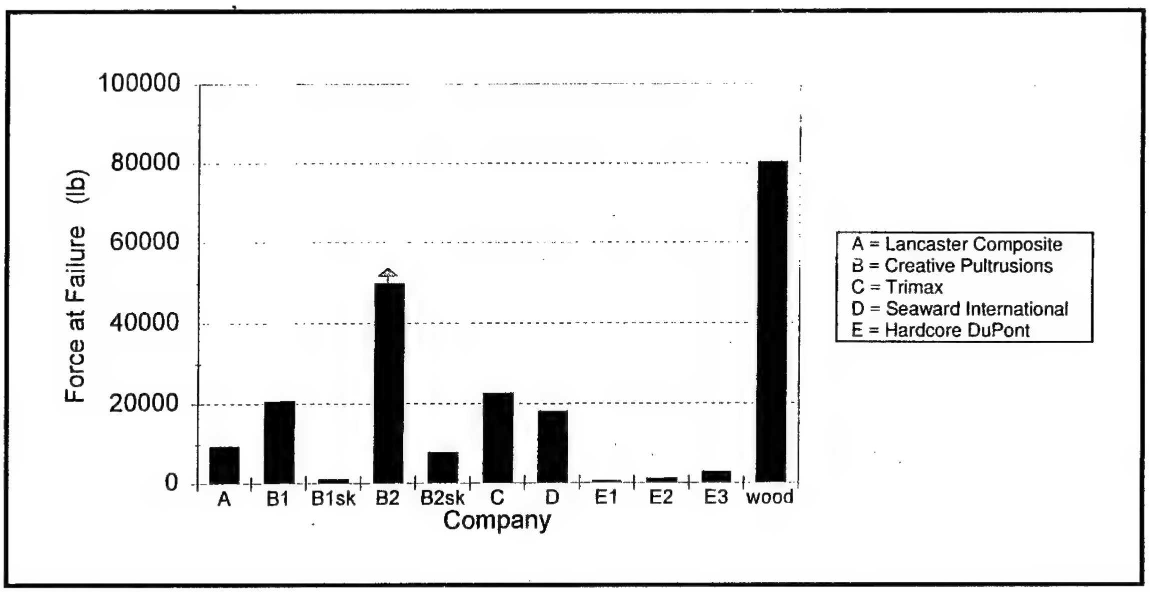

Figure 8. Force at failure of pile specimens tested in radial compression at -40 °F.

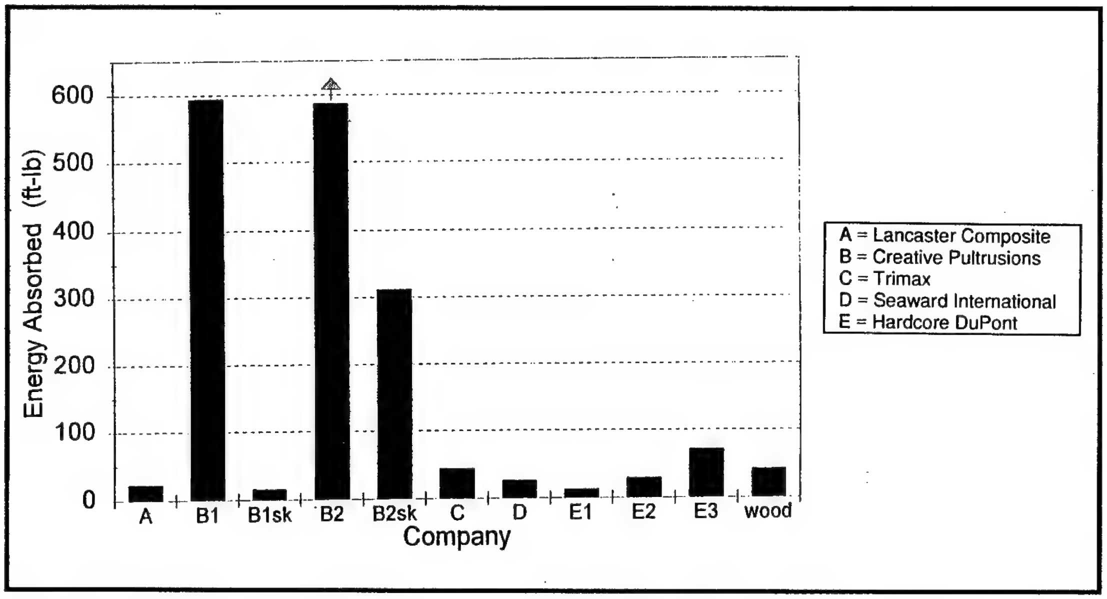

Figure 9. Energy absorption of pile specimens tested in radial compression at -40 °F.

Long Span Flexural Testing of Fender Pilings

For most modern marine facilities, fender pilings are designed to absorb the kinetic energy from vessels in bending. In this case, a critical engineering parameter that must be evaluated is the resistance of the pile to bending, or the product of the elastic modulus of the pile (E) and the area moment of inertia of the pile (I), commonly referred to as bending stiffness. In a four-point bending test, EI is determined from the measured data:

$$EI = \frac{Pa}{48\delta}\left(3L^2 - 4a^2\right) \qquad \textbf{Eq 1}$$

where:

E = Young's modulus of the beam materials, psi (Mpa)

I = moment of inertia, in^4 (mm^4)

a = distance between adjacent loading points, in. (mm)

L = distance between the two extremes

δ = deflection, in. (mm)

P = load, lbf (N).

And the outer fiber strain, ϵ, is given by:

$$\varepsilon = My / EI \qquad \textbf{Eq 2}$$

where:

M = applied moment

y = distance of the outer fiber from the neutral axis.

Flexural testing of all materials that make use of the standard solid mechanics closed form equations to calculate stress and strain from force-displacement data require fairly long spans. To neglect shear, ASTM recommends a minimum L:D ratio of 16:1 in their flexural tests. With pile diameters in the 12 to 16-in. range, this translates to specimen greater than 20 ft in length. Understandably, such large samples can be difficult to test, especially under controlled laboratory conditions. Room temperature testing of fender pilings under these conditions was performed at NFESC in California.

Long span testing in all cases was conducted with spans of at least 22 ft, in a modified four-point configuration. Two central loading nodes were used, from 6 in. to 2 ft apart. Samples were tested in the horizontal plane, nullifying the effect of gravity acting on the mass of the sample (Figure 10). Table 4 gives average results for the long span flexural tests. The data show all of the composite fender pilings tested at long spans exceeded the target EI of 600 x 10^6 lb-sq in. The composite pilings that fractured did so abruptly. Some piles exhibited localized buckling as the load steadily increased. These results are encouraging. They indicate that composite pilings can be substituted for traditional fender piling materials.

Short Span Flexural Testing of Fender Pilings

Short span flexural testing of fender pilings were performed under both room temperature conditions (70 °F), and sub-ambient conditions (–20 °F). The room temperature condition testing was conducted at Rutgers University in New Jersey (on a 10-ft span) for comparison with the long span testing performed under ambient conditions. This was done to estimate the magnitude of the error associated with the testing of composite pilings with L:D ratios of about 9:1, which was a limiting factor for subambient testing. Both ambient (room temperature) and subambient flexural testing (on a 9-ft span) was performed at CRREL in New Hampshire. Room temperature short span flexural testing at Rutgers University was performed in four-point mode, with loads located at one-third points along the 10-ft span (Figure 11).

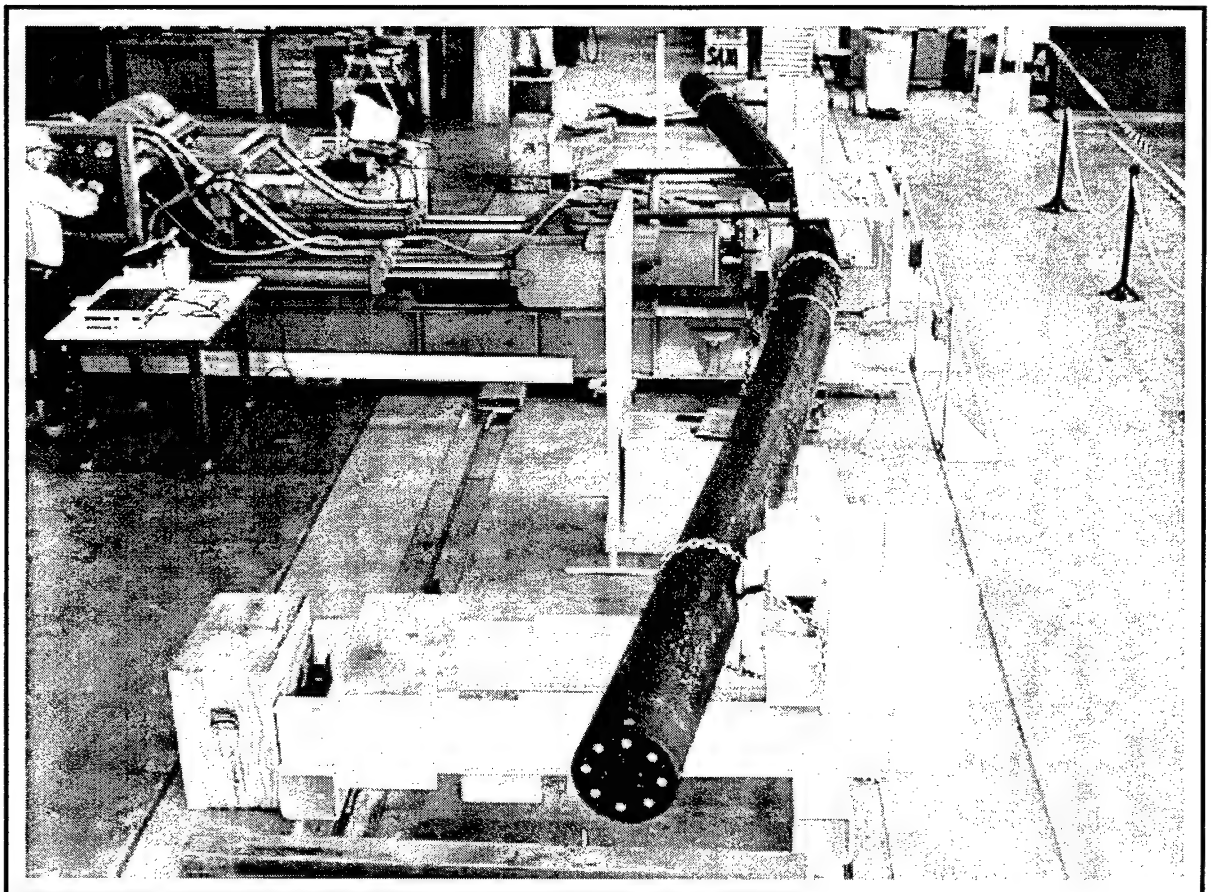

Figure 10. Four-point flexural (bending) tests at NFESC.

Table 4. Average test results for long-span flexural testing of fender piles.

Company	Number Tested	EI X 10^6 lb-sq in	Outer-fiber Fracture Strain ($\mu\epsilon$)	Max Load, Kips	Failure	Residual Deflection (in.)
Seaward International	2	910	18,000	23	Rebar Debond and Rebar Rupture	7 and 36
Hardcore DuPont Type A	3	1,050	5,667	10	Local Buckling	<1
Hardcore DuPont Type B	1	170	21,000	32	Composite Rupture	36
Timber*	many	1600				
Concrete**	many	4900				

* 12-in. diameter creosoted wood pile (Eaton 1978).
**18-in. square prestressed concrete section (Warren 1989).

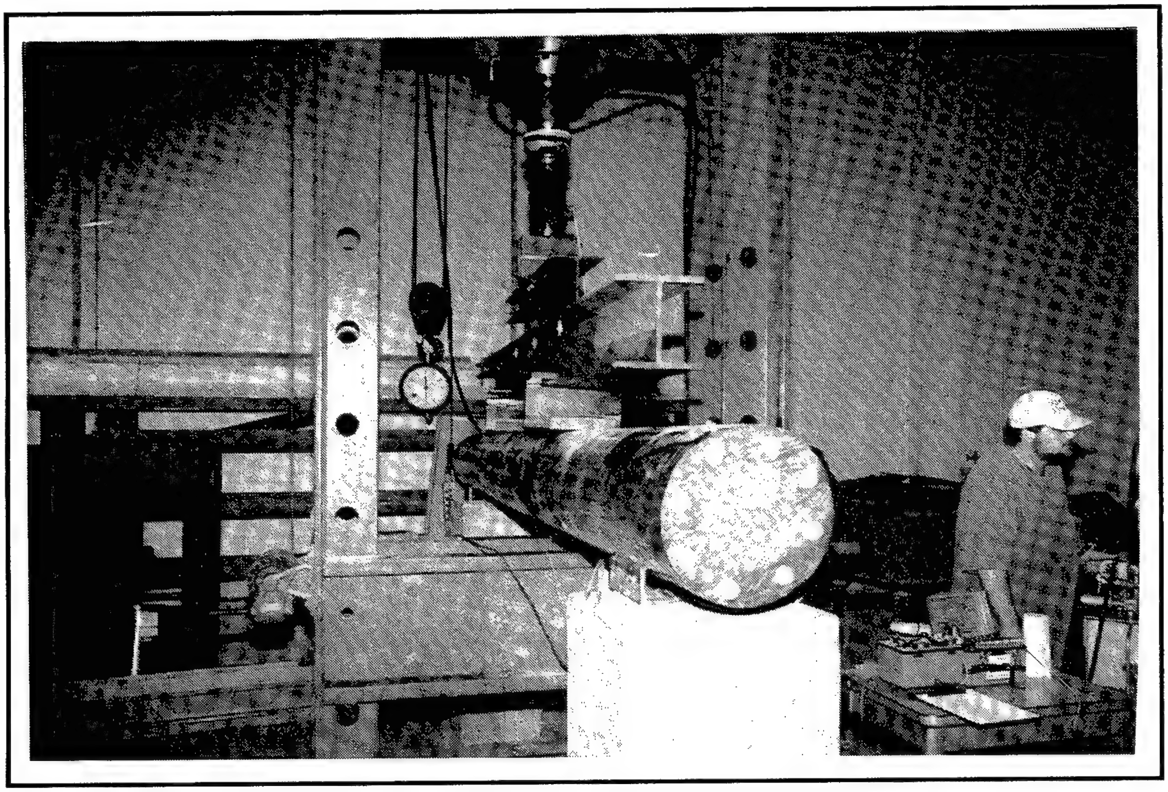

Figure 11. Four-point flexural (bending) tests at Rutgers University.

Note that, in some cases, the test specimens provided to Rutgers University for the short span flexural tests differed in composition and/or size from those provided for the cold radial compression tests. The flexural test specimens from Lancaster Composite were 13 in. in diameter compared to the 4-in. diameter specimens provided for the radial compression tests. This alleviated the necessity and possible errors due to scale-up. The Hardcore DuPont specimens for the radial compression tests were hollow while the specimens provided for the flexural tests were filled with concrete. The concrete fill would be expected to increase the bending stiffness of the pile. The Creative Pultrusions specimens sent to Rutgers University for the room temperature short span flexural testing consisted of the composite tic-tac-toe profile section encased in the HDPE tube cover, but without the plastic lumber inserts in the profile cavities. (Figure 5 shows the cross-sectional profile of the pile with the plastic lumber inserts.) Also, the Creative Pultrusions specimens were tested in flexure only in a nonskewed orientation; that is, with the webs and flanges of the tic-tac-toe profile at 0- and 90-degree angles to the plane of the loading fixtures. Table 5 lists the average results for short span flexural testing of composite fender pilings at room temperature.

Table 5. Average test results at room temperature for short span fender pile specimens.

Company	EI X 10^6 lb-sq in	Maximum Load, Kips	Failure
Lancaster Composite	1,155	84	Fracture of concrete core, followed by shell rupture
Creative Pultrusions	516	30.5	Buckling of web elements
Trimax	132	9.2	Yield, then fracture
Seaward International	580	89	Debonding of reinforcing bars, followed by matrix cracking
Hardcore DuPont	1,575	83	Fracture of concrete core, followed by shell rupture

A useful comparison is between the EI values measured using long spans and short spans for the only composite pilings that were equivalent to the short span testing. The 13-in. Seaward International piling was the only composite piling to be included in both tests. The long span EI for this piling was 910x 10^6lb-sq in., while the short span EI for this piling was measured at 580x 10^6 lb-sq in. This represents a 36 percent decrease in EI for the short span experiment as compared to the long span experiment.

This decrease is due to the fact that relatively significant deviations from the assumed closed form equations exist at spans of less than 16:1 L:D ratios for flexural experiments. This results in (presumably constant) errors for all of these measurements. (As spans become shorter, shear deformations become more important in the total load-deformation relations.)

In any event, the Lancaster Composite and Hardcore DuPont samples surpassed the target EI value of 6 x 10^8 lb-sq in. in these measurements. If one accounts for the error associated with using short spans, the Creative Pultrusions and Seaward International pilings exceed the target as well. Only the Trimax samples fell short of meeting the target EI values. This is certainly due, in part, to this piling being submitted as only a 10-in. diameter piling.

Room and low temperature short span flexural testing of composite fender pilings were performed at CRREL in Hanover, NH (Figure 12). The purpose of this set of experiments is to determine if the temperature dependence of the plastic matrix material comprising the composite pilings would limit the usefulness of the piling at low temperatures. This is evidenced by determining if the pilings could withstand an outer fiber bending strain of 2 percent at –20 °F. (Note: essentially every type of wood fractures at a strain of about 0.7 percent.)

Samples were conditioned at temperature for at least 24 hours until the interior of the pilings stabilized to the test temperature. In some cases, the simple act of cooling the pilings produced noticeable changes to the piles, owing to the

differences in thermal expansion of the various components. For example, both the Lancaster Composite and the Hardcore DuPont pilings had concrete protruding about 0.25 to 0.5 in. beyond the composite tubes at each end at the low test temperature (Figure 13). In addition, the hoop stress generated in the Hardcore DuPont samples on cooling caused cracks along the piling axis, but in the subsequent test at the applied maximum load (100,000 lbf), the specimen did not fail.

Both room and low temperature short span flexural testing was performed in four-point mode, with loads located at one-third points along the 9-ft span. For correlation between experimental set-ups at both locations, room temperature testing was performed up to approximately 1/3 the failure load observed for these pilings at room temperature at Rutgers University. Table 6 shows the data generated on short spans at both room and low temperature at CRREL.

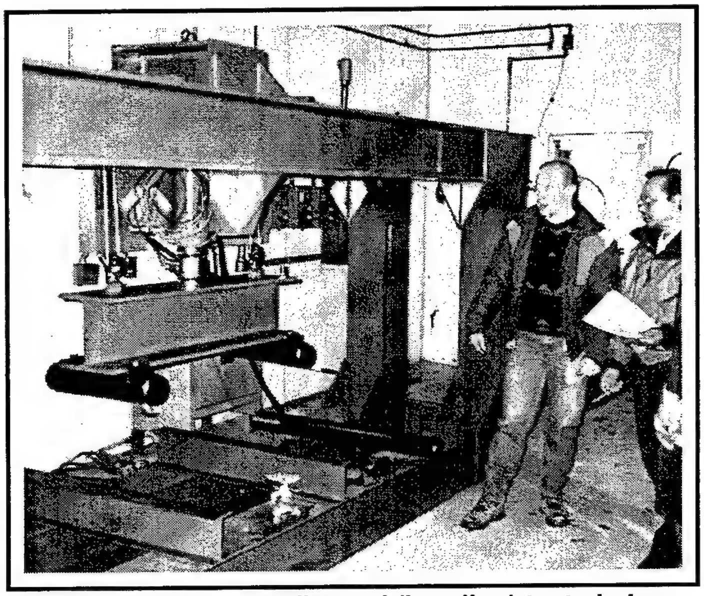

Figure 12. Four-point flexural (bending) tests in low-temperature room (-20 °F) at CRREL.

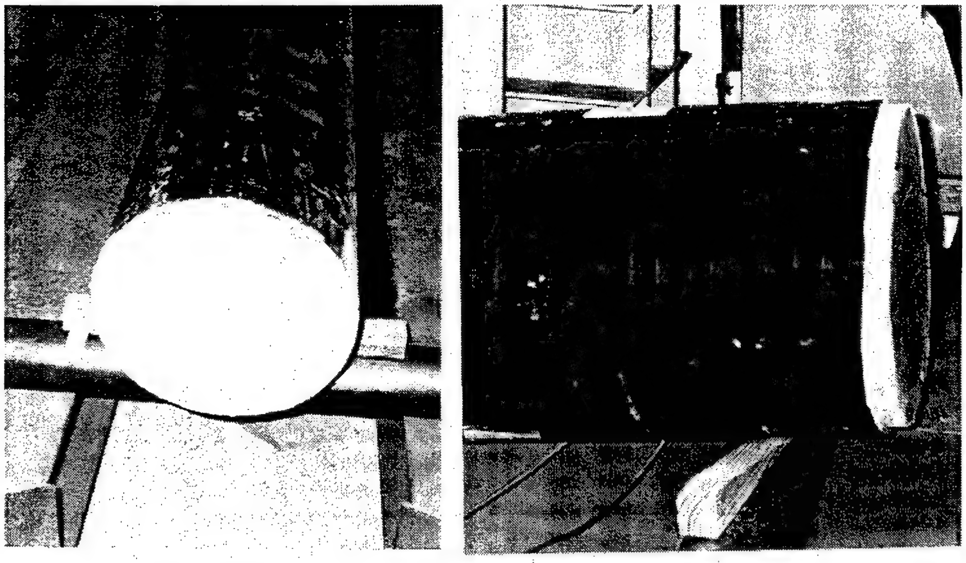

Figure 13. Slight protrusion of concrete core following conditioning of specimen to -20 °F for 24 hours.

Table 6. Average test results at room temperature and -20 °F for short span fender pile specimens.

Company	EI at room temperature (lb-sq in X 10^6)	EI at -20 °F (lb-sq in X 10^6)	Outer-fiber fracture strain at -20 °F (με)
Creative Pultrusions, Inc.	551	583	6,538
Seaward International, Inc.	644	621	7,750
Trimax	123	236	6,025
Lancaster Composite	1,180	1,056	10,233
Hardcore Dupont Composites	1,187	1,993	8,880

Figure 14 shows a set of room-temperature test load-deflection curves. Failure load of the Trimax piling in flexure was first seen in this experiment, and the other pilings were only loaded to 1/3 of their observed failure at Rutgers University. The failure load of 8,730 lbf seemed quite low. The Lancaster Composite pilings yielded slightly at around 18,000 lbf, producing small cracking noises (possibly due to localized slippage and/or crushing of the concrete core within the shell). This piling continued to accept higher loads up to 30,000 lbf. Loads on the other specimens continued to increase monotonically with deflection.

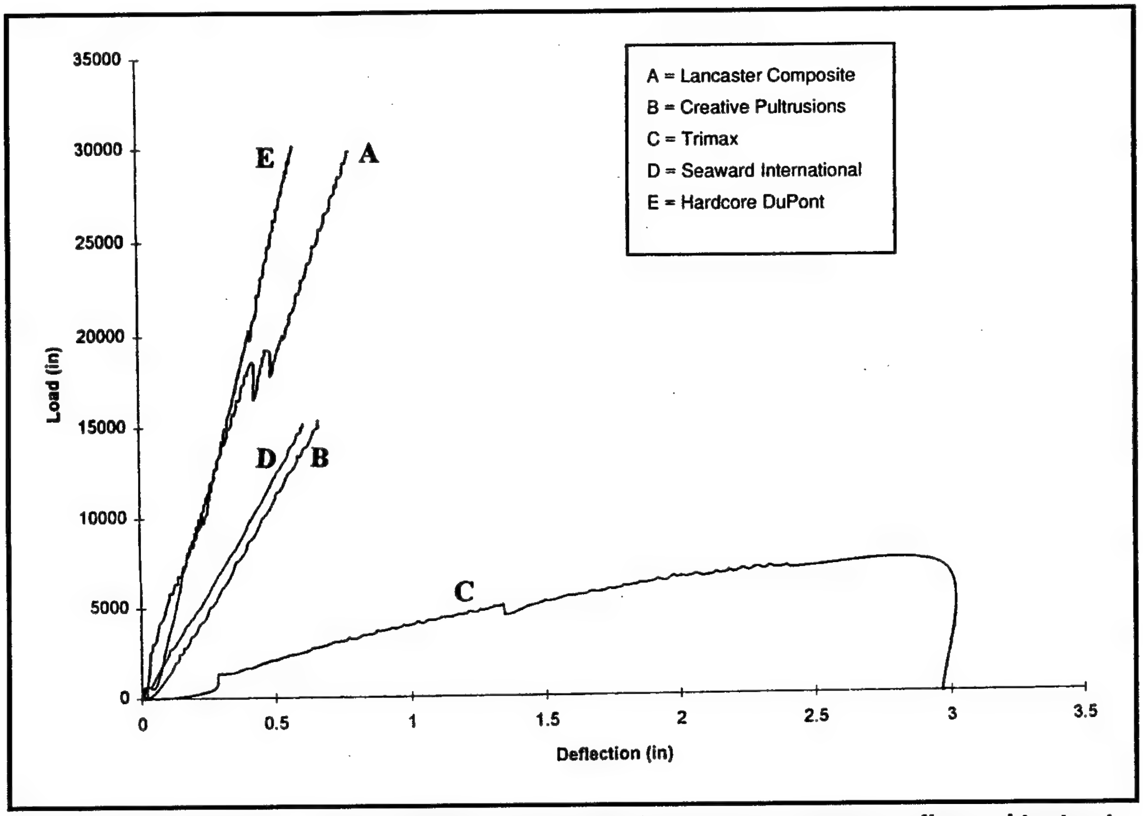

Figure 14. Superimposed load-deflection curves for room-temperature flexural tests at CRREL.

Figure 15 shows the low temperature load-deflection curves on a representative set of experiments. As might be expected from composition, the concrete-filled composite tubes of Lancaster Composite and Hardcore DuPont accepted much higher loads than the other specimens. Lancaster Composite pilings failed at a load barely exceeding the capacity of the machine (100,000 lbf), but continued to exhibit a yielding type of behavior as the load increased. Both Creative Pultrusions and Seaward International also produced intermediate cracking and yielding as the load was increased, but continued to accept load until a final brittle failure was observed (Figure 16). The Trimax piling, with a diameter of only 8.75 in. as opposed to the other specimens with diameters of approximately 12.75 in., failed catastrophically at a fairly high deflection (Figure 17).

Loadbearing Pile Tests

For fender piles, EI is important relative to absorbing the energy from a berthing vessel. For an axially loaded loadbearing pile, stiffness is important relative to the resistance to buckling. Column buckling can especially be a problem when driving the piles.

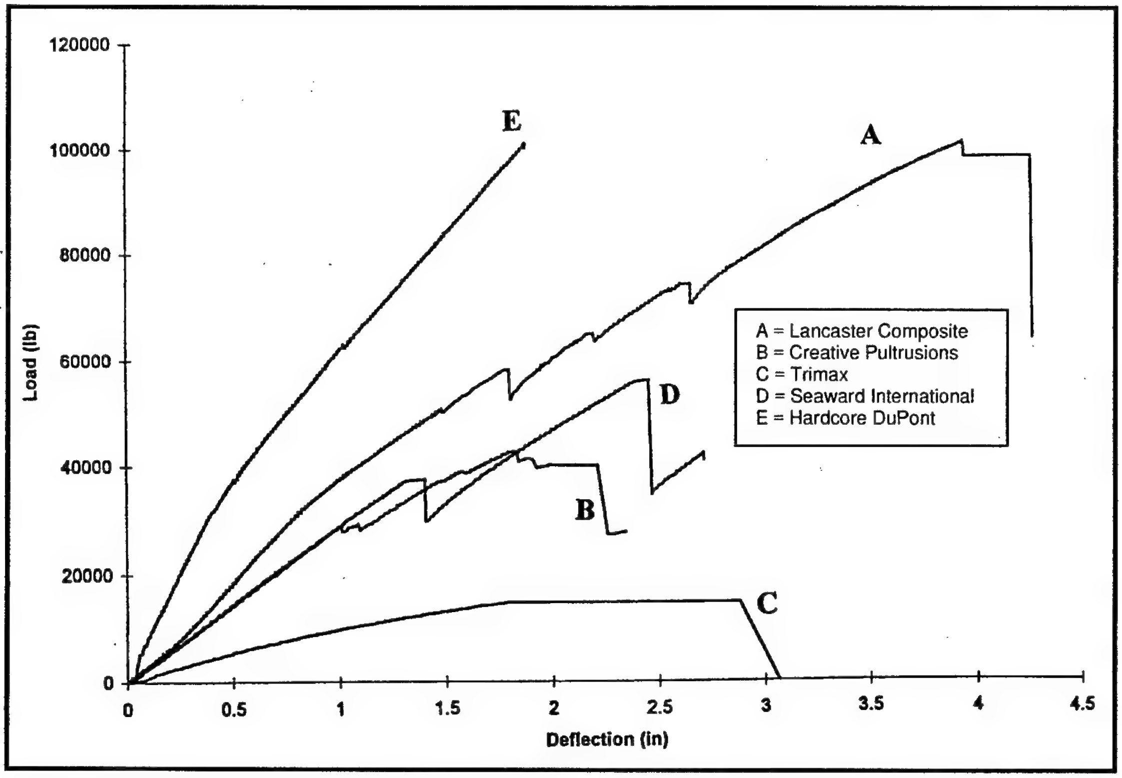

Figure 15. Superimposed load-deflection curves for flexural tests performed at -20 °F at CRREL.

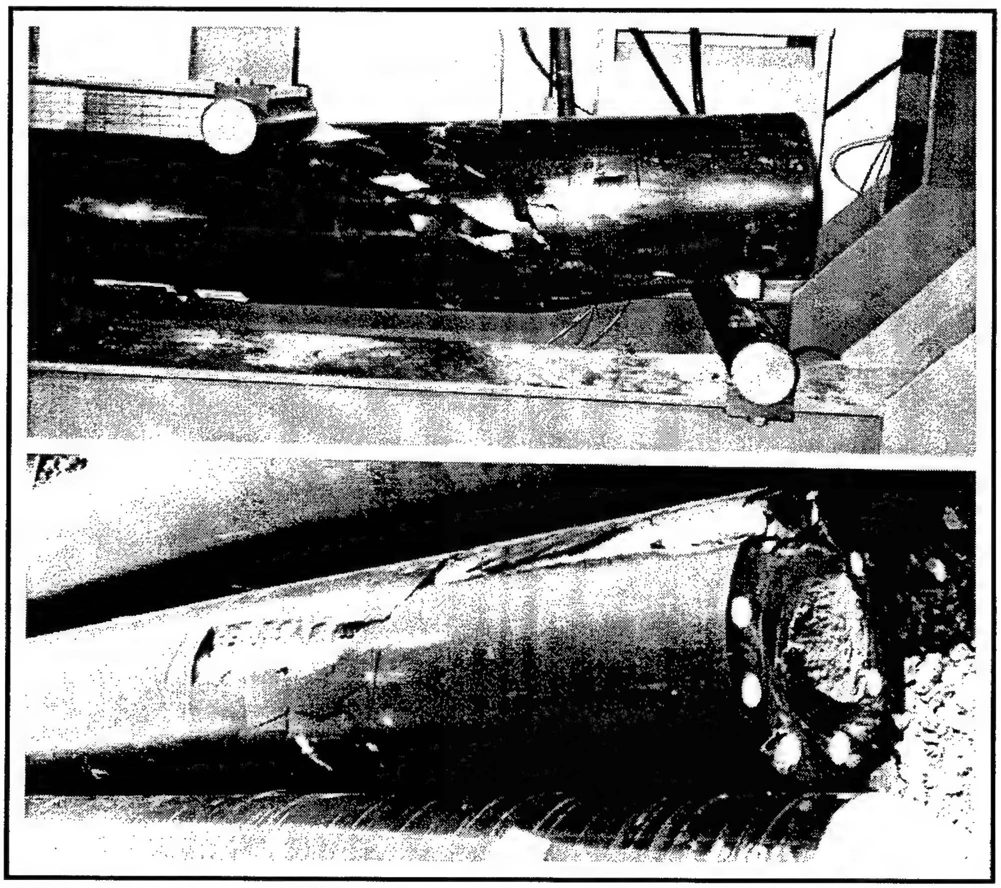

Figure 16. Low-temperature (-20 °F) piling failure with extensive fracturing.

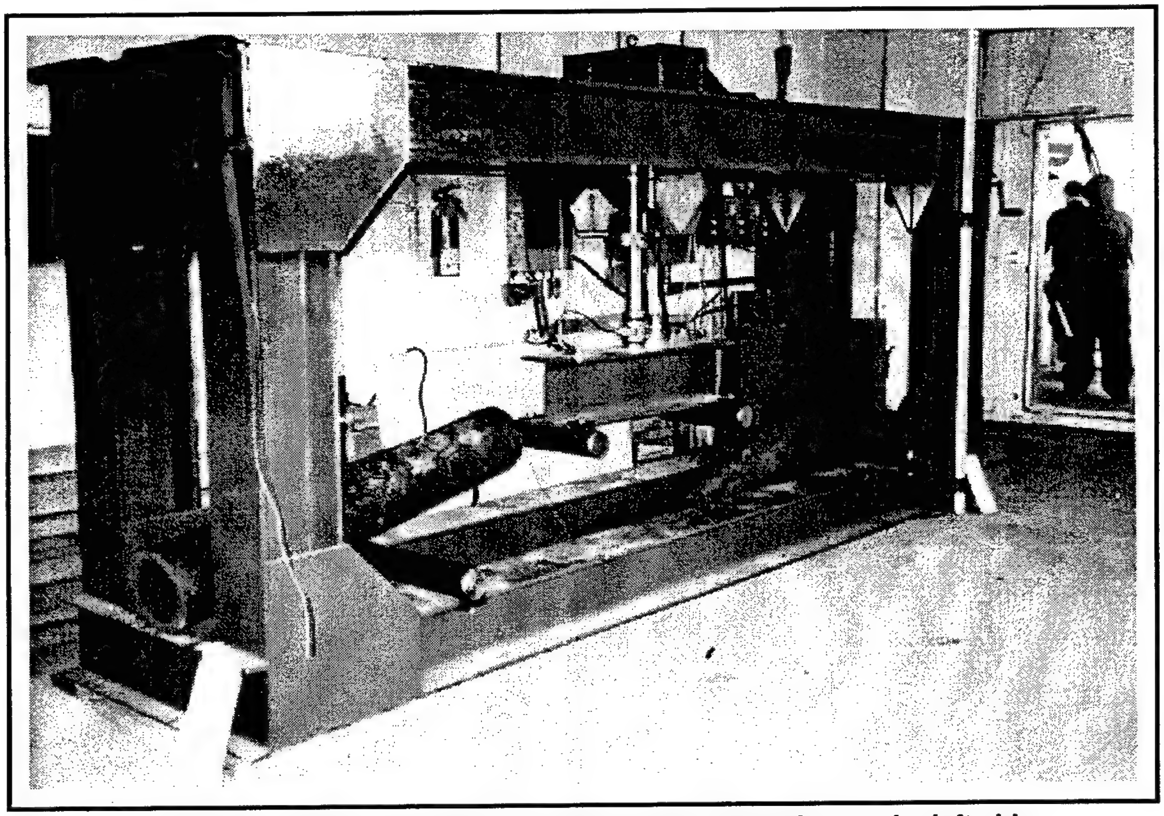

Figure 17. Specimen failed so violently at failure that the section on the left side flipped over in the test fixture.

However, bearing piles can be subjected to lateral loads from wave action, ice, and debris flows that could induce flexural failures. Flexural testing was therefore performed on the loadbearing piles virtually in the same manner as the fender piles. Given that the primary function of a loadbearing pile is to take an axial compressive load, compression tests were performed at room temperature to determine compressive strength and load capacity. Given the viscoelastic (i.e., having both viscous and elastic properties) nature of the polymer materials that these composite piles incorporate, creep (permanent deformation under long-term loading) is another important property to consider. Two of the manufacturers, Hardcore DuPont and Lancaster Composite, supplied specimens consisting of concrete-filled composite tubes. As was done with the composite fender piles, wood loadbearing piles were used as a basis to set the Performance Target Goals for the composite loadbearing piles. By virtue of the concrete fill, these composite pilings would be expected to compete as a replacement for reinforced concrete pilings.

Flexural "Screening" Testing of Bearing Piles

Flexural tests were performed at ambient temperature by NFESC on bearing pile specimens from four different manufacturers. (Originally, six different

manufacturers submitted specimens for testing. However, two of the six manufacturers made corporate decisions to no longer pursue this application, or remain as part of this CPAR project. Results from these manufacturers' specimens are not presented as part of this report.) Although two pile designs did not meet the qualitative performance targets, they were considered to be drivable and thus met the intent of the screening test and were slated for further testing.

Compression Testing of Bearing Piles

Compressive tests using a 850 kip testing machine were conducted at USACERL on the four different bearing pile types. Specimens approximately 5 ft in length were used to minimize buckling phenomena. Figure 18 shows a typical test setup. The measured data from the experiments was the compressive load applied and the crosshead displacement of the machine. Additionally, one of each of the five composite piling systems specimens had strain gages attached to measure the axial and transverse strain during testing.

The ends of the piling systems were cut by machining to be as parallel as possible. The remaining length was in the range of 57 to 59 in. The specimens were placed in the testing machine and centered on the compression platens. The MTS testing machine was operated in stroke control with a testing rate of 0.05 in. per minute. Testing was conducted until the specimen failed, or until the machine reached its capacity. For all of the tests, the load and crosshead displacement were continuously recorded.

On one specimen of each composite piling type, four strain gages were attached. On the tic-tac-toe specimen from Creative Pultrusions, the gages were attached at the axial midpoint, at the centers of the box midpoints, all in the axial direction. On the specimens with circular cross sections, three strain gages were attached at the axial midpoint, in the axial direction, at the third points around the circumference. The fourth gage was located at the axial midpoint, in the transverse direction between the first and third axial gage. On specimens with strain gages, the strains were also continuously recorded during testing. Table 7 gives results of the compression tests.

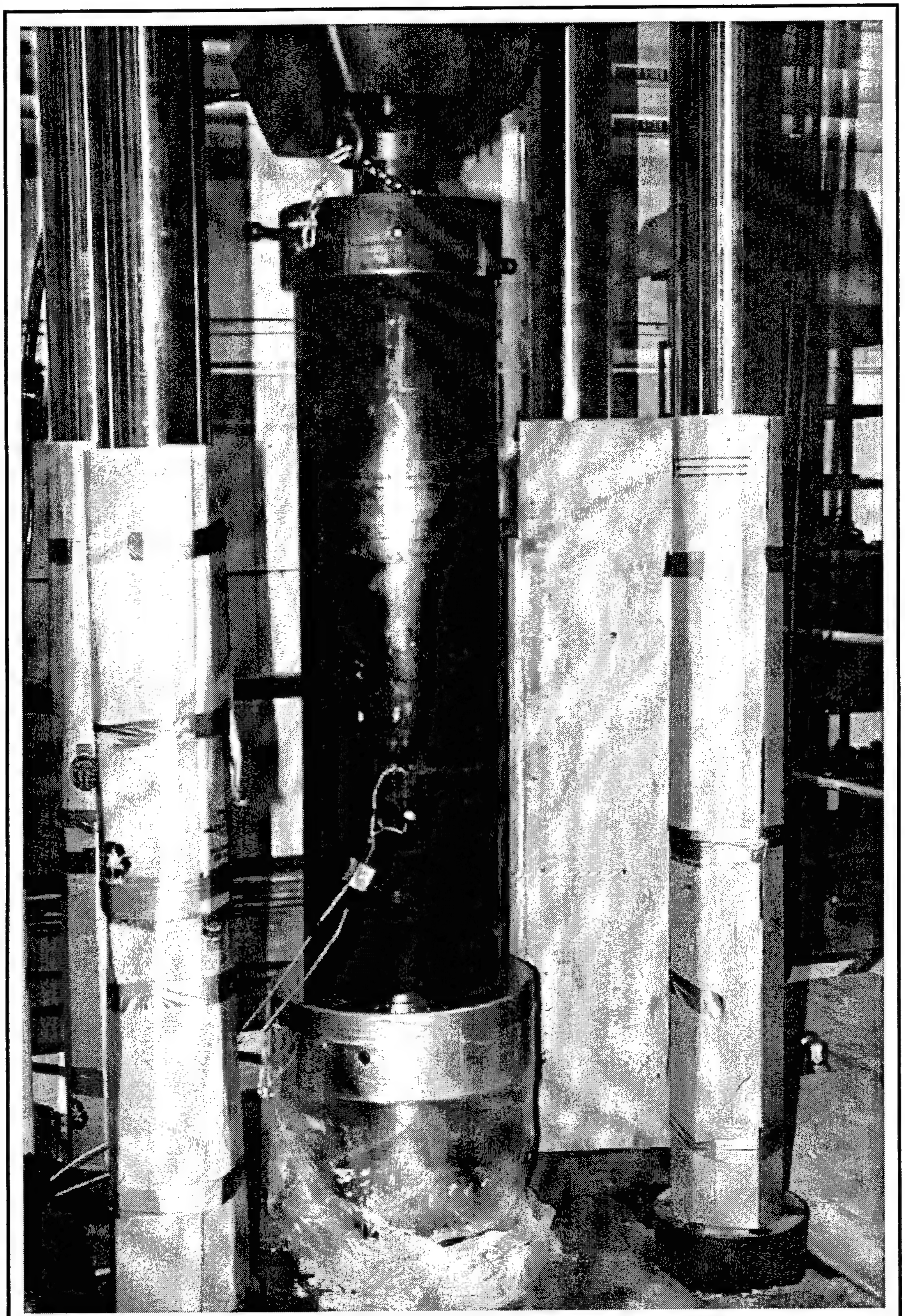

Figure 18. Typical setup for the compression testing of the loadbearing piles.

Table 7. Bearing pile compressive test results.

Manufacturer	Compressive Failure Load, kips	Cross-Sectional Area, sq in	Compressive Failure Stress, ksi	Modulus, E, psi x 10^6
Creative Pultrusions	248.5	14	17.8	5.10
Hardcore Dupont Composites	765.6	148.5	5.15	0.85
Lancaster Composite	>856*	130	>6.58	1.15
Seaward International	>856*	201	>4.26	0.55
* Did not fail.				

The tic-tac-toe shaped piles from Creative Pultrusions failed at approximately 250 kips and did not meet the established minimum load capacity of 704 kips. The piles from Lancaster Composite and Seaward International did not fail at the limit of the testing machine (850 kips). Surprisingly, the concrete filled piles from Hardcore DuPont exhibited a yield point at approximately 500 kips and failed at approximately 765 kips. This failure may have been a function of the quality of the concrete. Figure 19 shows the failed concrete filled Hardcore DuPont pile. Figure 20 shows the stress (psi) versus the strain (in/in) for the four different pile types. Figure 21 shows the compressive load (lb) versus the displacement (in) of the pile. Figure 20 shows that the Creative Pultrusions pile is actually the "stiffest" composite. However, its overall load capacity was not very great since the actual cross-sectional area of the tic-tac-toe profile is almost an order of magnitude less than the pile with next smallest cross-section. The Hardcore DuPont pile exhibited a pseudo-ductility.

Creep Testing of Bearing Piles

Although creep is an important consideration with piles made from polymeric materials, conducting long-term creep tests on the candidate piles was beyond the resources and the schedule of the project. (Consideration to perform such tests was actually an add-on beyond the original Performance Target Goals.) To determine if any viscoelastic (creep) effects due to testing rate could be observed, the compression tests were conducted at several different strain rates.

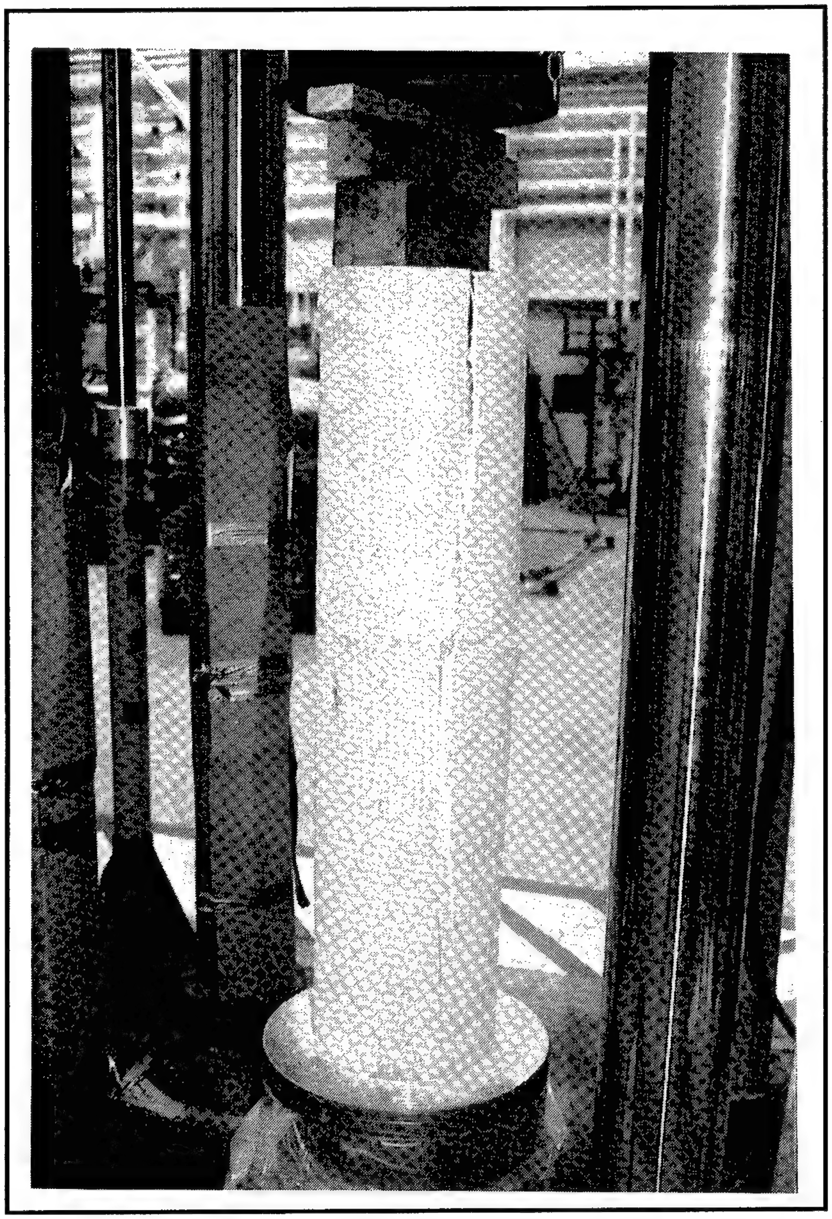

Figure 19. Failed concrete-filled FRP composite pile.

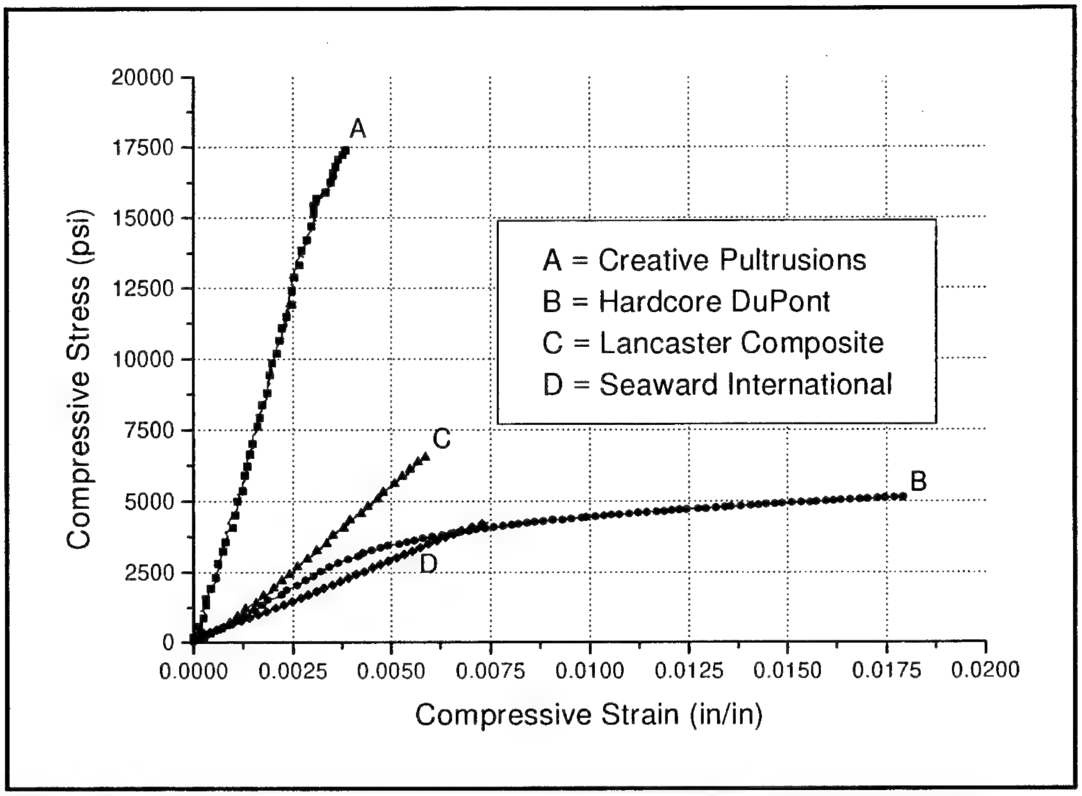

Figure 20. Stress (psi) versus the strain (in/in) for the four different pile types.

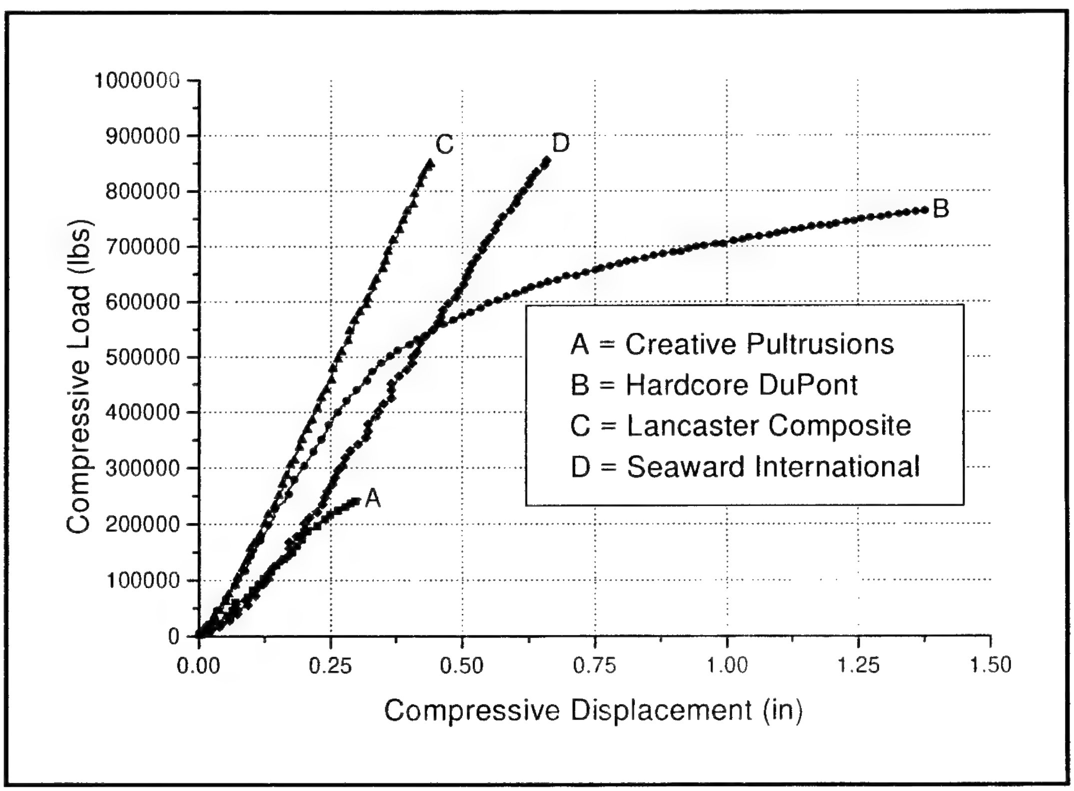

Figure 21. Compressive load (lbf) versus the displacement (in) of the pile.

Sheet Pile Tests

Flexural "Screening" Tests on Composite Sheet Piles

Specimens of sheet piles from three different manufacturers were tested in flexure by Rutgers University. Because the specimens from Creative Pultrusions and International Grating had a corrugated profile, a special test fixture had to be fabricated for each product to get an accurate reading of stiffness (Figure 22). The pile specimens from Trimax where a tongue-in-groove profile with flat sides. A surprising result to the screening tests was that none of the specimens tested met the minimum requirements for EI of even the light duty sheet piling as given in the originally established Performance Target Goals. A restructuring of the Goals was, therefore, performed based on experimental results and performance use requirements.

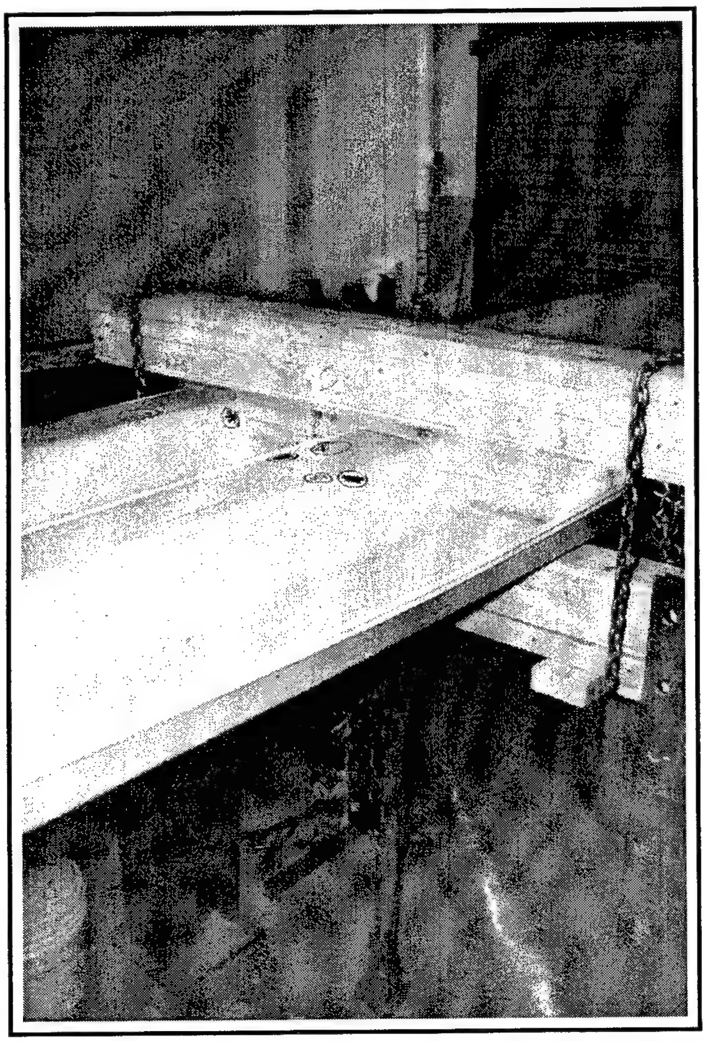

Figure 22. Special fixtures needed to test corrugated sheet piling in bending.

Light-Duty, Grade 2	5×10^3 - 1×10^4 kip sq in./ft
Light-Duty, Grade 1	1×10^4 - 5×10^4 kip sq in./ft
Medium-Duty, Grade 2	5×10^4 - 1×10^5 kip sq in./ft
Medium-Duty, Grade 1	1×10^5 - 5×10^5 kip sq in./ft
Heavy-Duty, Grade 2	5×10^5 - 1×10^6 kip sq in./ft
Heavy-Duty, Grade 1	1×10^6 - 5.5×10^6 kip sq in./ft

All three submitted sheet pilings had experimentally determined EIs (Table 7) that placed them in the Grade 2, very light-duty category as given above. Since all three products tested represent commercial products already in service in various applications, plans were made to complete the rest of the tests on these products to collect additional performance data. The "double-pile" configuration refers to two piles connected together to make a wider panel. Testing in this configuration also tests the joint between panels.

Initially the hope was to be able to design and fabricate a heavy-duty composite sheet pile that would have the mechanical properties equivalent to PZ-27 steel sheet piling (EI = 5.5×10^6 kip sq in./ft). However, initial design efforts indicated that such a composite sheet pile was not commercially viable and further optimization of materials and geometry would need to be investigated.

After performing the initial flexural tests, it was observed that one of the products had a corrugated profile that lent itself to being connected together to increase the moment of inertia, I, which would thus increase the bending stiffness, EI. The researchers at Rutgers took two of the panels and attached them together using adhesives and pop rivets to form a new modified panel profile. A honeycomb profile was created by connecting two of the modified panels connected together (Figure 23). Bending tests were performed on this honeycomb profile both with and without a concrete fill in the hexagonally shaped tube that results when the modified panels are connected. Table 8 lists the results of these tests. Even greater stiffness might be achieved if measures are taken to increase the bond between the composite tube and the concrete fill.

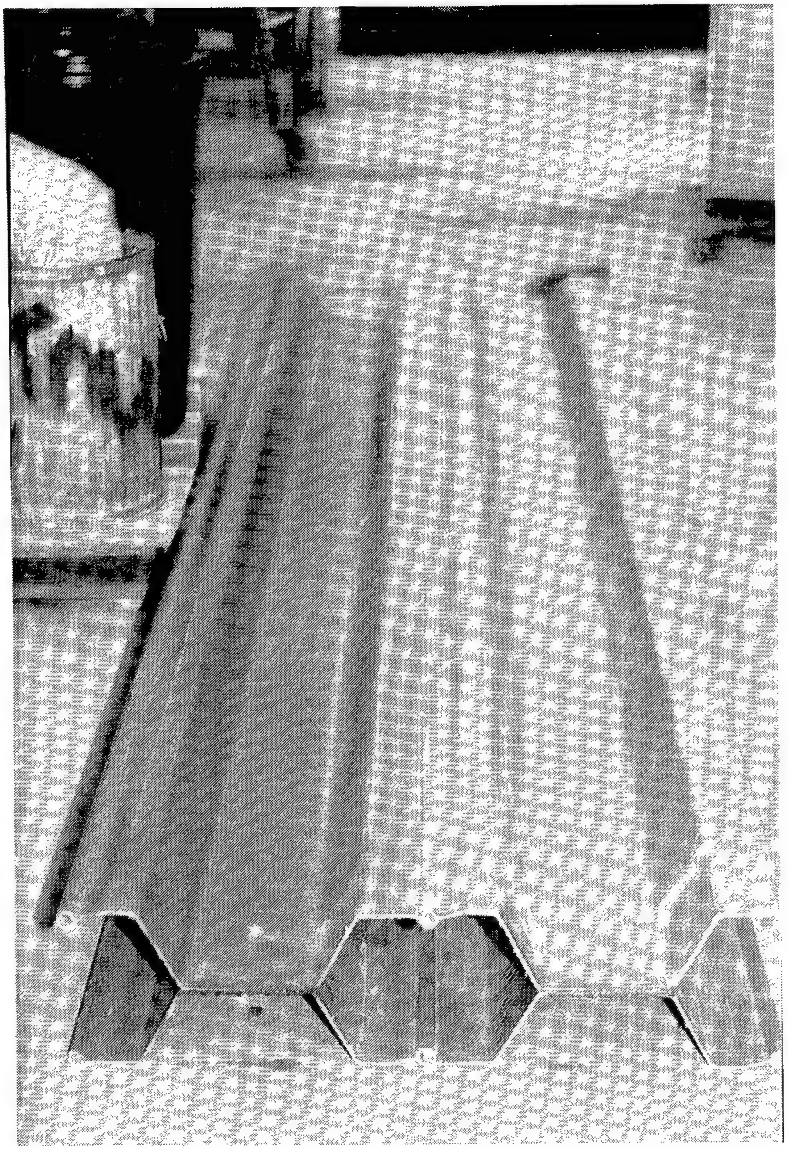

Figure 23. Honeycomb profile created by connecting sheet piling sections together.

Table 8. Property changes as a result of sheet pile modifications (International Grating composite sheet pile).

	As Is	Honeycomb	With Concrete
Span (in)	108	108	107
Maximum Load (lb)	1,092	1,300	11,600
Maximum Moment (in-lb)	39,312	46,800	620,600
EI (kip-sq in./ft)	4.22×10^3	9.97×10^3	3.62×10^4

5 Field Demonstrations

Tiffany Street Pier

As part of another CPAR project on plastic lumber products, CPRR and USACERL personnel developed a working relation with the New York City Department of General Services (NYCDGS) and their construction of the Tiffany Street Pier, a recreational pier constructed using materials made from recycled plastics (Lampo and Nosker 1997). During the initial stages of this CPAR piling project, NYCDGS personnel presented the CPAR Piling Project with the opportunity to install some fender piles at the Tiffany Street Pier. With NYCDGS concurrence, off-the-shelf composite-type fender piles and composite structural elements adapted for use as a fender pile were installed (Figure 24).

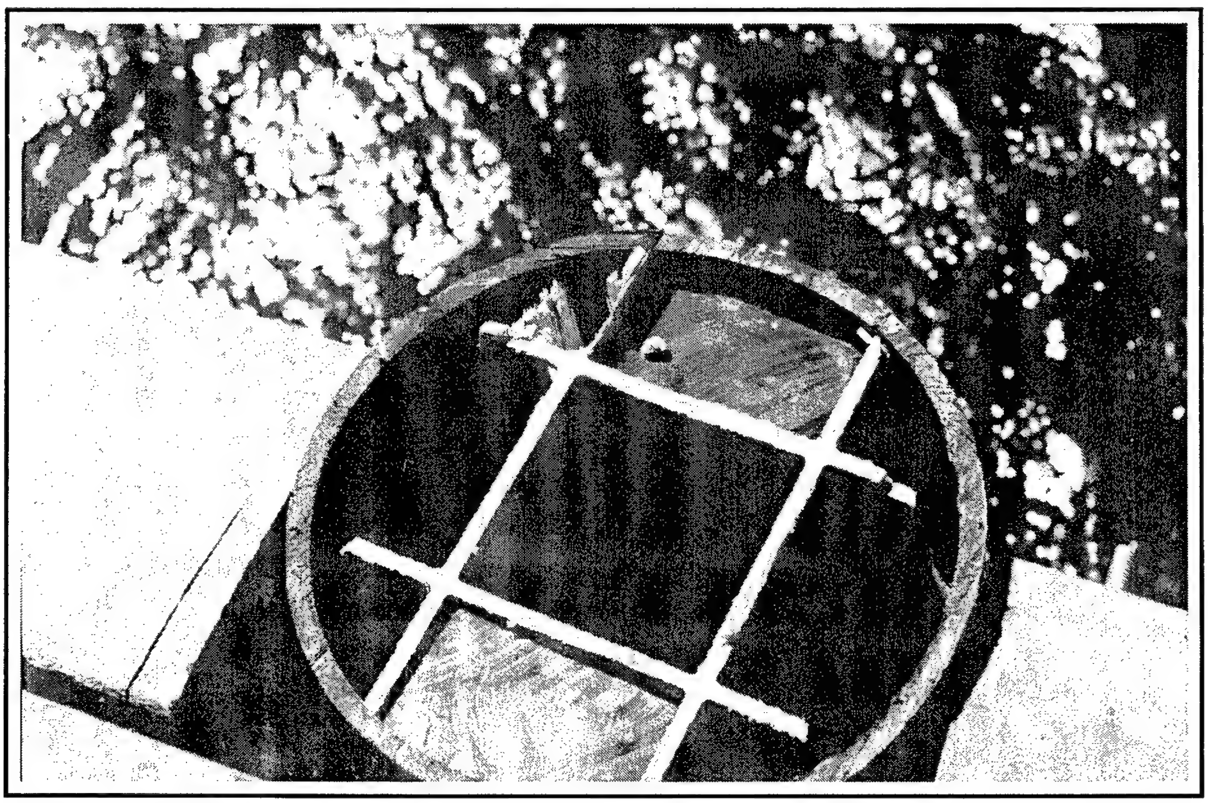

Figure 24. Creative Pultrusions' fender piling system installed at Tiffany Street Pier, New York City, NY.

This installation was done before the CPAR team did any laboratory testing on the candidate pile designs. The Team's involvement was to learn from an actual installation of piles and not to demonstrate the piles from this CPAR Piling Project. A site inspection of the pier was conducted during April 1996. Several loadbearing piles that were installed during the original pier construction have a steel pipe in the core. (Note that these piles are not of the type being developed under this CPAR Project.) Cracks were observed on many of these steel-core piles (Figure 25). The majority of the cracks were in the hoop direction; however, a few axial cracks were also observed. All of the fender piles installed as part of the CPAR Project appeared to be in excellent condition.

On 3 August 1996, a major fire occurred on the Tiffany Street Pier. Reportedly lightning struck the steel cored piles on the gazebo during a severe thunderstorm. The fender piles installed as part of this CPAR project were involved in the fire. Figure 26 shows the remains of the composite fender pile installed at the far end of the pier. The plastic lumber inserts and the polymer-matrix material in the tic-tac-toe profile section were consumed in the fire. (Figure 24 shows the pile before the fire.) The high-density polyethylene piles used in the pier were also significantly damaged by the fire. This fire emphasizes the need to address fire performance issues of these polymer-matrix piling materials comparatively with timber piling. The pier project did not specify any fire performance requirements.

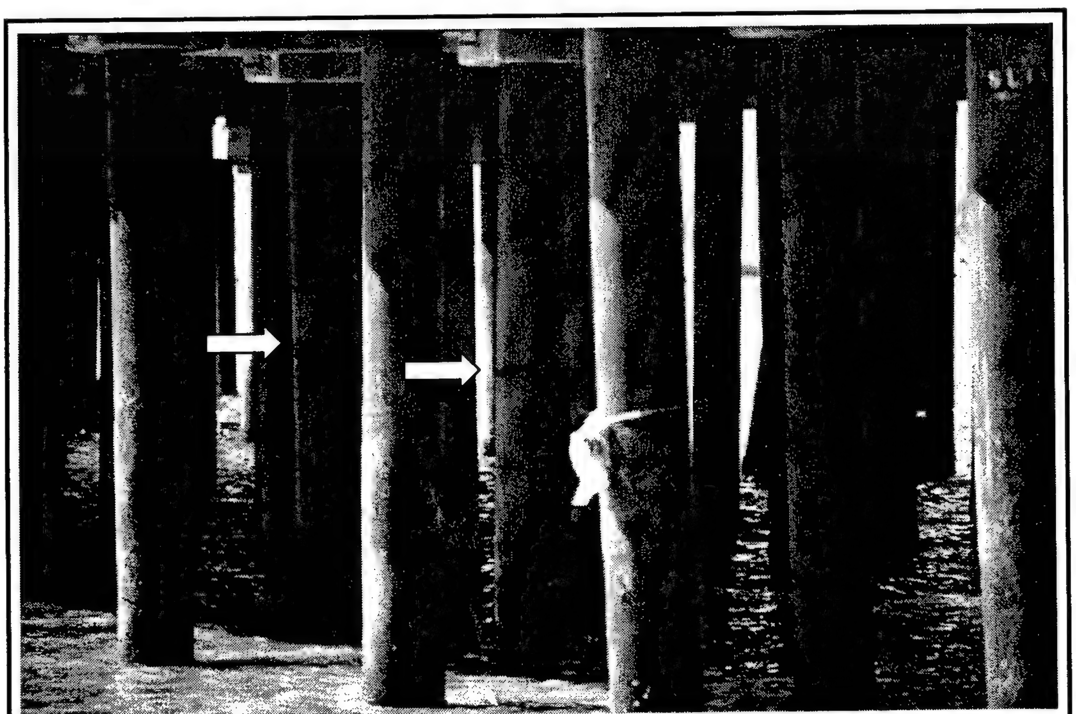

Figure 25. Cracking of steel-cored HDPE piles within 1 year of installation at Tiffany Street Pier.

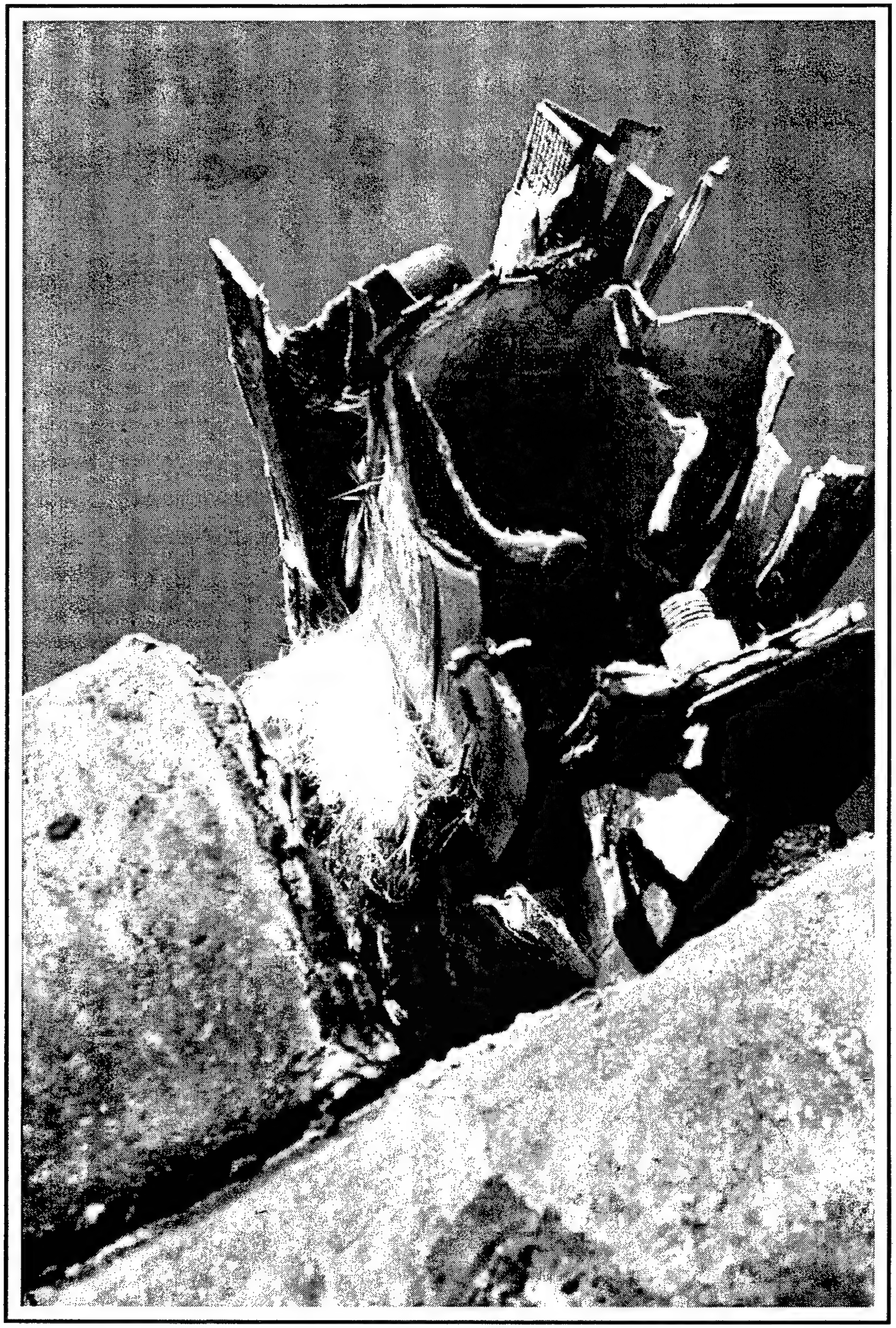

Figure 26. Condition of the FRP composite fender pile shown in Figure 24 after the fire at the pier.

Port Authority of New York/New Jersey

The Port Authority of NY/NJ hosted a 2-day Project progress meeting in September 1995. The meeting participants were given a tour of the Port of Newark facilities to get a first hand look and appreciation of the deterioration their piling systems undergo due to the mechanical impact and rubbing from ships and barges and attack from marine organisms. Port Authority engineers discussed their needs for advanced piling systems and their willingness to use their port facilities for the demonstration of composite piling systems as developed in this CPAR Project.

As the initial screening tests for the fender piles were being completed, the PA NY/NJ approached the Project Team about installing demonstration test piles at their Port Newark facility. The PA NY/NJ wanted to complete the installation of fender piles at Port Newark before the Winter of 1996. Composite fender pilings from Creative Pultrusions, Seaward International, and Trimax were selected for installation at Piers 7 and 9 at Port Newark, NJ, in October 1996. (Note that these selections were made largely using the results of the cold radial compression test that was developed from specific site conditions at Ports Elizabeth and Newark.) Figure 27 is a schematic showing the common design of a pier structure at this location. Piers 7 and 9 were chosen because of the harsh environment, where wood piles typically must be replaced every 6 years, on average. Under these circumstances, a premium composite pile would require the fewest number of years to be cost-effective relative to a timber pile. That is, if the composite pile can survive the onslaught of huge ships, stray barges, and tugboats, making direct contact with the pile (i.e., no camels used to distribute the forces) during hot summers as well as cold winters.

Figure 28 shows the three different types of pilings waiting for installation. The pilings to the left were made by Seaward International, which had diameters of 13 in., were 60 ft in length, and were comprised of an extruded 100 percent recycled, high-density polyethylene (HDPE) blend reinforced with eight glass/polyester pultruded rebars. The piles in the middle were manufactured by Trimax, which had diameters of 10 in., were 60 ft in length, and contained 75 percent recycled HDPE, 20 percent chopped fiberglass, and 5 percent of a proprietary additive. The pilings on the right were manufactured by Creative Pultrusions, which had diameters of 13 in., were 60 ft in length, and were comprised of a pultruded glass/vinyl ester tic-tac-toe profile and a HDPE cover (bumper) on the upper third of the pile (above the waterline).

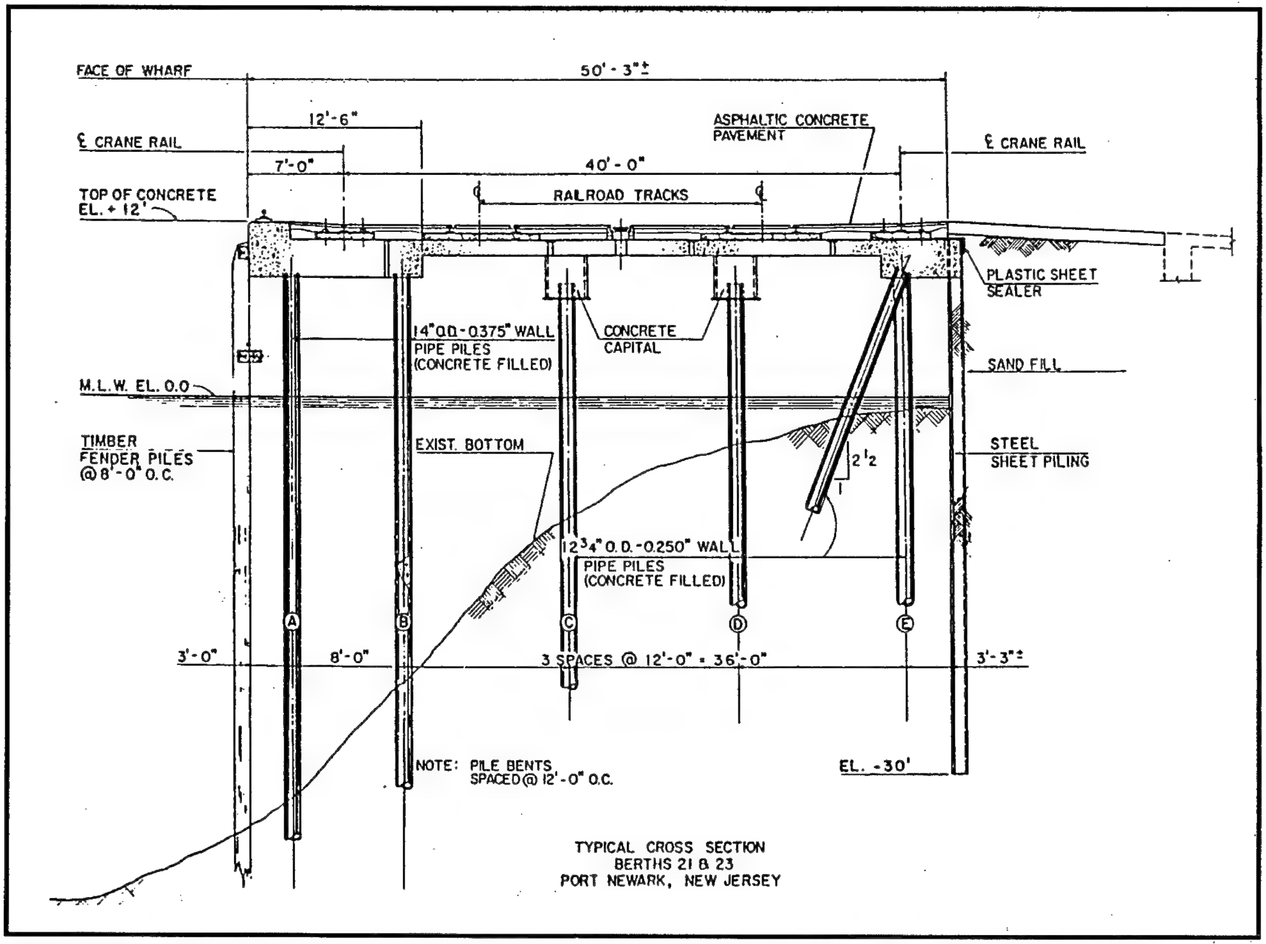

Figure 27. Typical construction details for pier at Port Newark, NJ, (courtesy the PA NY/NJ).

Each pile was a continuous length without splices. (The length of these composite piling products are typically limited by shipping restrictions rather than fabrication constraints.)

Eight composite pilings of each type were installed consecutively, with a few wooden piles placed between each type. Figure 29 shows some of the installed demonstration piles. A 9B3 hammer, which exerts 8750 lbf, was used to drive the piles (Figure 30). The contractor considered those composite pilings that required no special treatment beyond that required for wooden pilings, to be "easiest to install." The tic-tac-toe shaped pilings from Creative Pultrusions required on-site assembly of slipping the HDPE cover over the upper portion of the tic-tac-toe profile. Figure 27 shows the cover already installed. This assembly considerably increased installation time especially when the HDPE cover shrunk in the cold temperatures along the waterfront to where it was a very tight fit over the tic-tac-toe profile. The lead end of the 10 in. diameter Trimax piles had to be tapered to a point on-site to minimize wandering of the tip during driving (Figure 31).

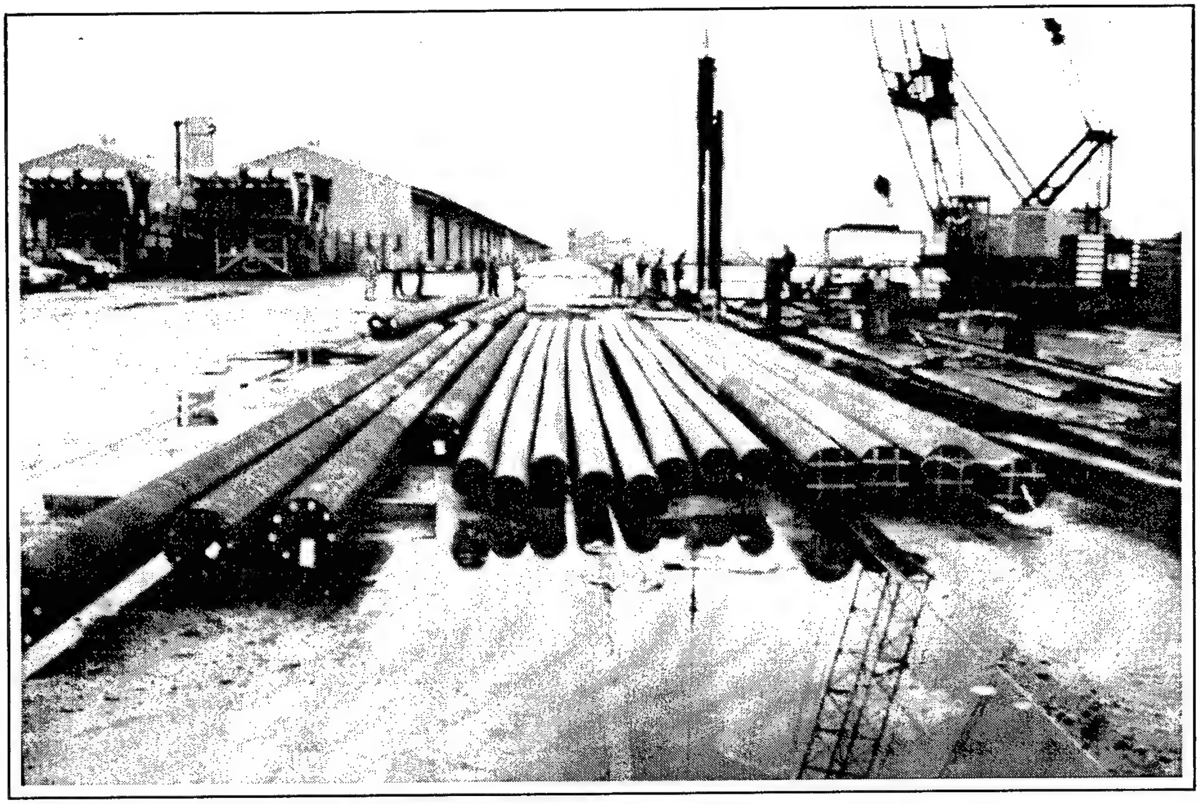

Figure 28. The different demonstration fender piles waiting to be installed.

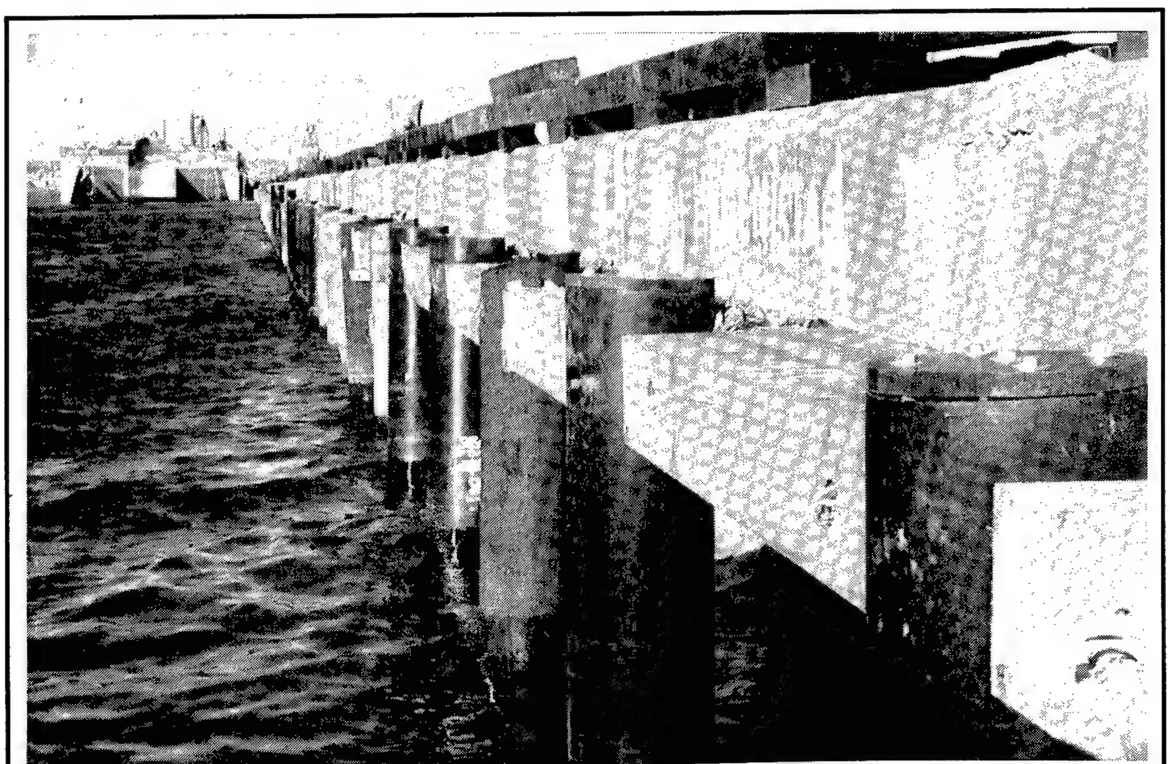

Figure 29. Installed demonstration piles at Port Newark, NJ.

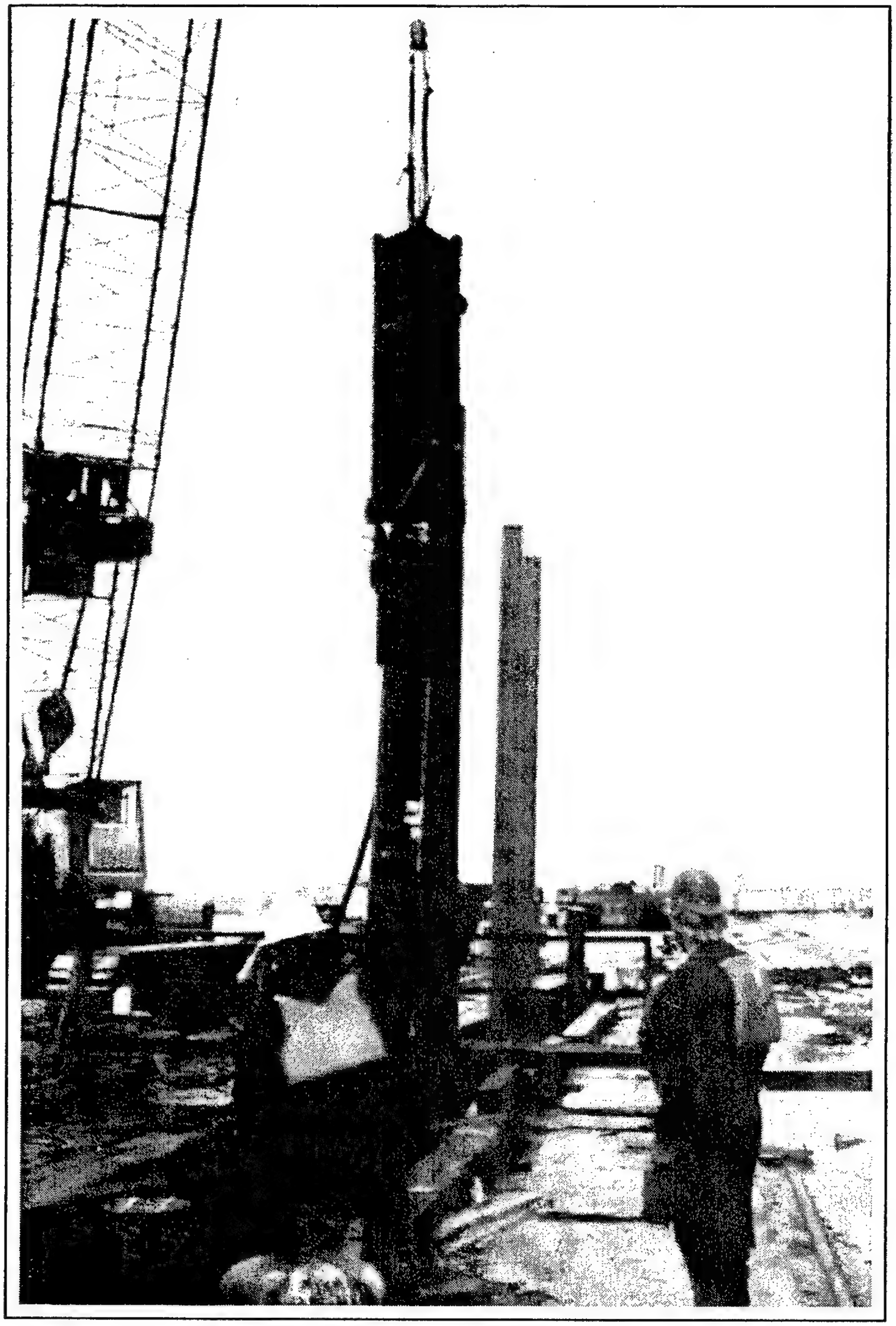

Figure 30. Driving of the fender piles.

The overall installation configuration and geometry were the same as traditional wood piles at this installation, including 6-ft on center spacings, and through-bolting the piles to the walers with 1-in. diameter bolts at two locations: near the top of the piles and 10 ft below the top, as required by the PA NY/NJ. The bolt holes were countersunk with 4 in. diameter holes for a washer and nut. (Each manufacturer was to specify if any particular fastening method or hardware was required to properly install their piles.)

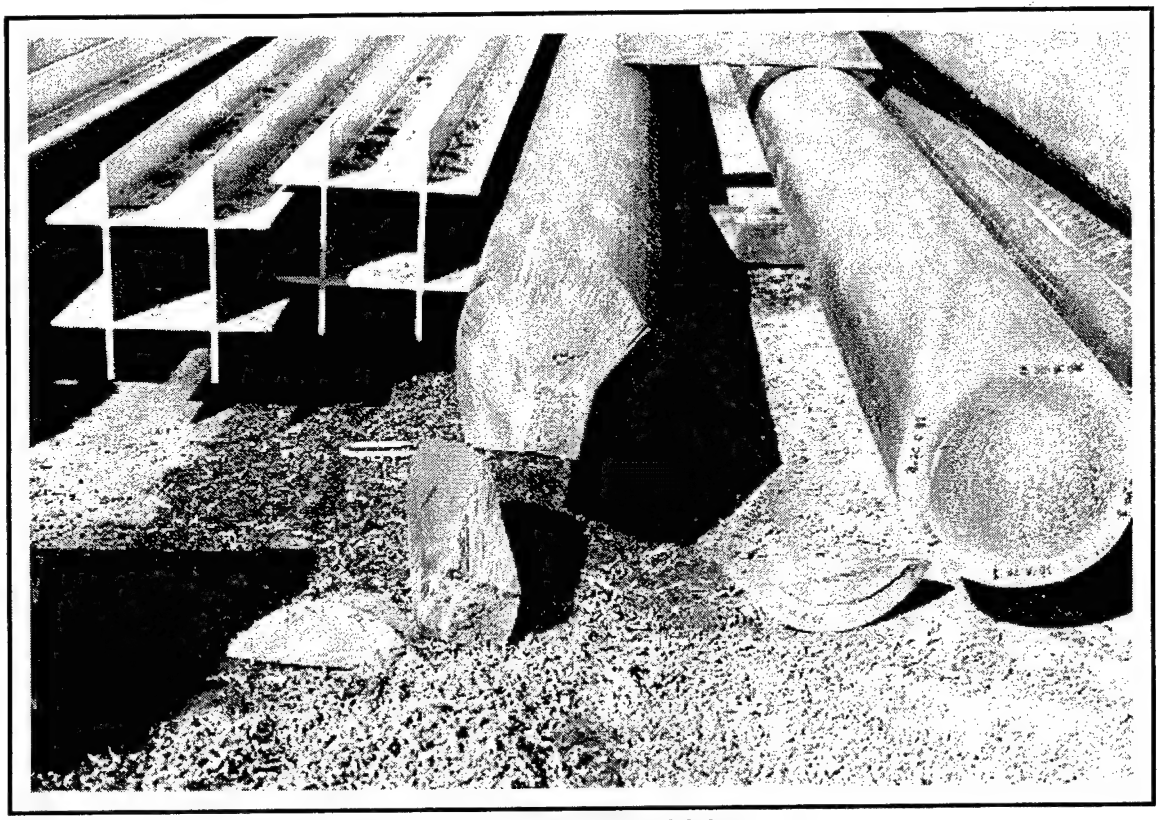

Figure 31. Tapering of the Trimax piles to facilitate driving.

For comparison, the composite piles are measured every 6 months relative to how far they protrude beyond the waler to monitor movement and wear (Figure 32). No noticeable changes have been observed by this measurement. However, the chopped fiberglass reinforced HDPE pilings from Trimax have shown a type of failure. Cracks have been observed that coincide with the drilled fastener holes. The cracks appear to be normal to the piling axis (Figure 33). These pilings were submitted as 10 in. round pilings and not the standard 13 in. diameter pilings. It is felt that the stress-raising effect that a 4 in. hole has on a 10 in. diameter piling is much greater than the stress-raising effect that a 4 in. hole has on a 13 in. diameter piling. In retrospect, these 10 in. diameter pilings should have been installed differently using a design that would not unduly weaken the pile at such a critical load point. One possibility might be a strap fixture that attaches to the back (pier) side of the pile.

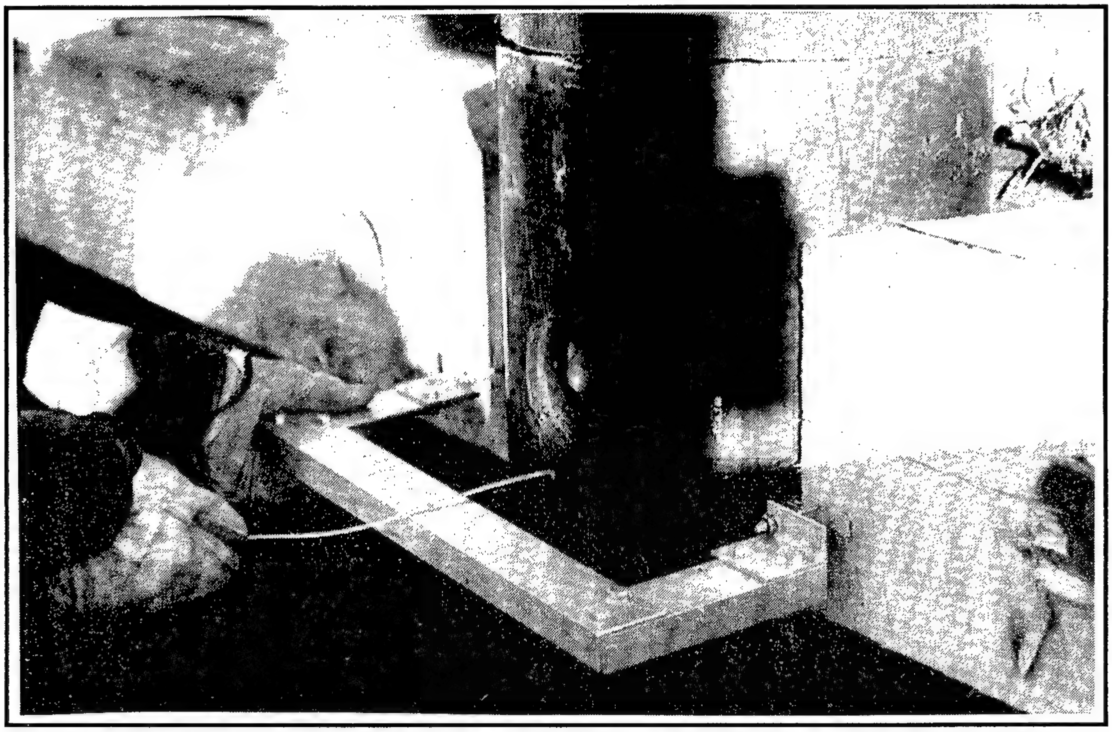

Figure 32. Measurements taken by the Port Authority NY/NJ to monitor movement and wear.

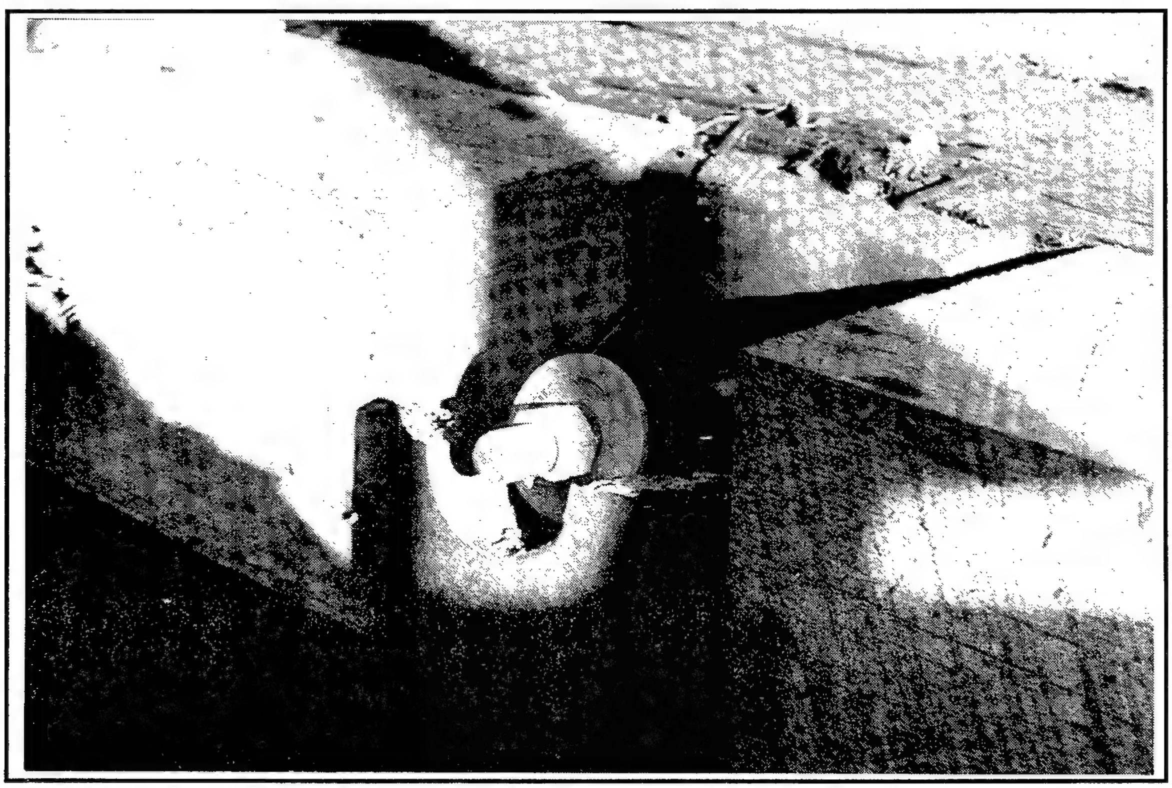

Figure 33. Loss of section of pile where cracking had occurred.

6 Discussion

Fender Piles

The laboratory testing of mechanical properties showed that composite fender piles are viable substitutes for wood and prestressed concrete fender piles. However, the test data should be used with a degree of caution since the number of tests performed on any one type piling was not statistically large enough. The test methods developed and used by this project are being used as a starting point by a newly formed ASTM group on Systems for Marine/Waterfront Applications (Committee Section D20.20.04) for developing test methods for fender pilings. While there are many other important properties, the two most important properties of fender piles for which there are no standardized test methods to determine are EI (bending stiffness) and radial compression (pinch).

During the installation of the demonstration fender piles at Port Newark, several issues were highlighted. One issue is the need to perform driving tests on the piles to determine their ability to be driven in a normal manner. Another important issue is the choice of fastening procedures and hardware to connect the pile to the pier and/or other appurtenances. With the diversity of design and composition, the fasteners and the procedures will likely need to be further developed product by product.

Unfortunately, project resources and time prevented researchers from installing the concrete-filled composite fender piles as part of this project. However, both Hardcore DuPont and Lancaster Composite have since had their fender pilings installed in commercial port facilities. Lancaster Composite piles were selected for a demonstration project to replace the original timber pile and wale system protecting the Lake Pontchartrain Causeway Bridge near New Orleans, LA (Figure 34). This demonstration is being conducted by the U.S. Army Waterways Experiment Station, Vicksburg, MS, as a separate but related project.

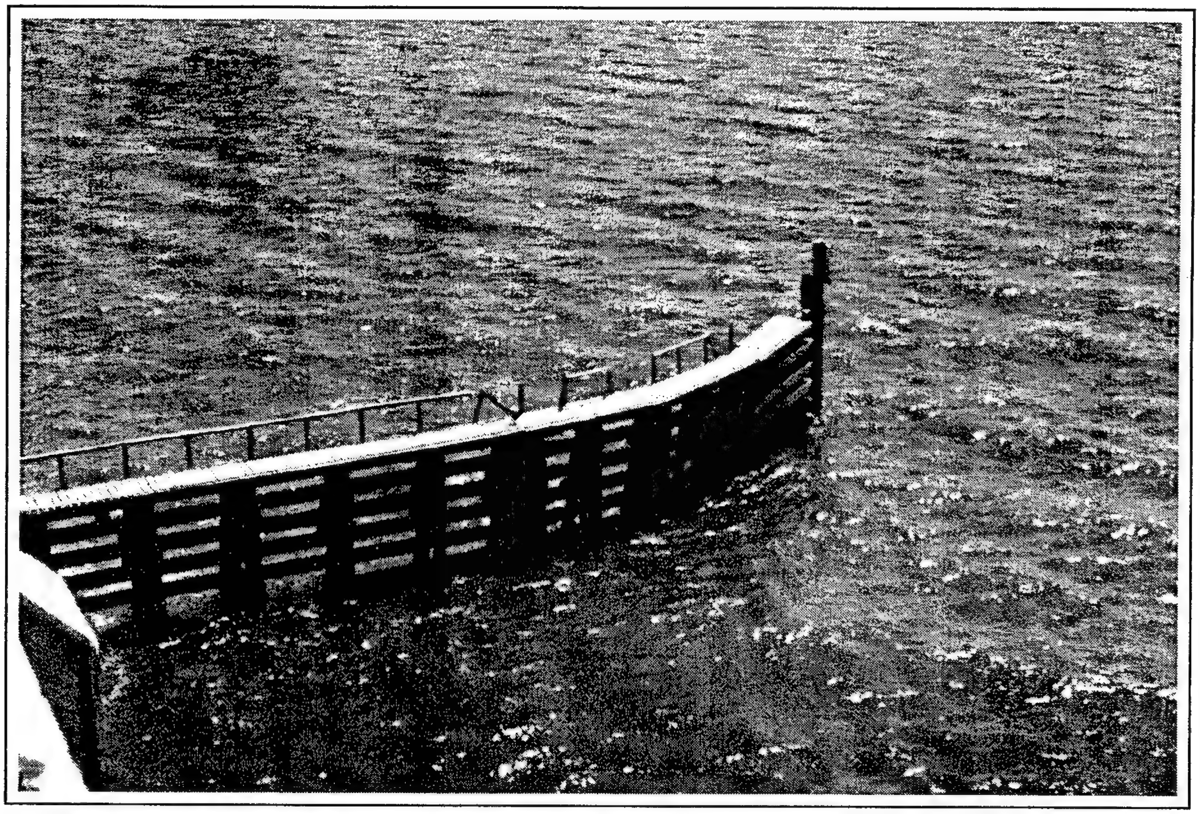

Figure 34. Lancaster Composite piles selected for system protecting the Lake Pontchartrain Causeway Bridge near New Orleans, LA.

Loadbearing Piles

The future application of composite loadbearing piles for marine/waterfront structures appears promising. However, several issues need to be further investigated before widespread application of these products as substitutes for structural concrete components. Piling driving analyses must be performed on these piles to achieve a better understanding of their load capacity and behavior, but also to better understand the pile-to-soil interactions and the stability of the pile in the ground. Creep of the pile is also important especially when the piles contain polymeric components under load. Site-specific performances need to be evaluated for the use of composite piles in loadbearing applications much the same as they would be for concrete and/or steel piles. This project did not identify a field demonstration opportunity for the loadbearing piles. As these piles are used for such loadbearing applications, the piles should be strain gaged and instrumented to measure long-term deformation, especially where the loads can be quantified and are fairly stable over time.

Sheet Piles

The future for continued use and developments for composite sheet piling appears to be bright. U.S.-made hot-rolled sheet pilings are quickly becoming unavailable. (U.S. Steel is ceasing production of hot-rolled sheet piling.) While this project did not produce a replacement for PZ-27 steel sheet piling, advancements were made on how that might be accomplished economically. This work is expected to continue in a new project on Composite Gates and Sheet Piling under the Corps of Engineers High-Performance Materials and Systems Program. As with the loadbearing piles, creep is an important consideration with composite sheet piling; future studies must address this issue. Although a couple of opportunities were identified and pursued, a field demonstration of the sheet piling products being evaluated under this CPAR project did not materialize (due primarily to conflicts in issues related to project timing). Actually all three of the manufacturers have their off-the-shelf products in service (very light-duty applications as defined within) in a variety of locations with no reported problems.

General

The piling systems being developed, evaluated, and demonstrated by this CPAR project were, in retrospect, a large undertaking. The diversity of materials and design between the piles from the different manufacturers and the sometimes unrelated aspects between the different pile types (e.g., fender versus sheet), made it a challenge to address all the important issues for each of the products and different systems within budget and scheduling constraints. Yet, even though there were some shortcomings, a lot of worthwhile information and publicity were accomplished by the project.

Specification Guide

Test methods and materials standards for the various piling systems as being developed and tested under this CPAR project are currently being addressed by an ASTM Committee Section D20.20.04 on Systems for Marine/Waterfront Applications. Some of the manufacturers have developed specifications for their particular products (Appendix C). Even within a particular piling system type (e.g., fender piles), the diversity of the different products presents a real challenge in developing a universal composite piling specification. Until ASTM or other appropriate industry consensus standards organization meets this

challenge, the following "Specification Guide" information is presented to assist the design engineer in developing his own specification or assuring that a manufacturer's specification covers the most critical items. This information combines the lessons learned during the course of this project with the originally developed Performance Target Goals. While several items are the same for each type composite piling, key critical items are unique and the specification guide is, therefore, presented for each type piling to avoid any confusion.

Specification Guide for Fender Piles

1. Required cross-sectional dimensions noting upper and lower limits and any shape restrictions.

2. Required total piling length and whether spliced sections are allowed.

3. EI determined experimentally using ASTM test method (currently under development). Until this method is completed, the test shall be conducted in a four-point bending mode on a full-sized pile specimen with an appropriate L:D ratio. If splices are allowed, a test must be conducted to show that the spliced section has properties equal to or greater than the unspliced section. To avoid brittle behavior, the outer fiber strain shall be 2 percent or greater at failure.

4. If the fender pile is to be used in a design where the pile is subject to a pinching action during the berthing process, determine the radial compressive properties per ASTM (method currently under development). Until this method is completed, suggest conducting a stress-strain test perpendicular to the pile axis at -40 °F at a strain rate of 100 percent per minute.

5. State if any special handling requirements are necessary due to the design or composition of the pile.

6. List any special techniques or fixtures required to drive the pile.

7. Detail fastening and joining methods especially if certain restrictions or limitations apply. If such special requirements apply, the pile should be so labeled. List and describe any special hardware needs.

8. The materials composition of the pile shall not pose a hazard to the environment through any leaching action.

Specification Guide for Loadbearing Piles

1. Required cross-sectional dimensions noting upper and lower limits and any shape restrictions.

2. Required total piling length and whether spliced sections are allowed.

3. EI determined experimentally using ASTM test method (currently under development). Until this method is completed, the test shall be conducted in a four-point bending mode on a full-sized pile specimen with an appropriate L:D ratio. If splices are allowed, a test must be conducted to show that the spliced section has properties equal to or greater than the unspliced section.

4. Load capacity of the pile as verified by axial compressive tests.

5. Using experimental data and structure design requirements, determine buckling stability of the piles.

6. Axial compressive creep data as determined on a full-sized pile specimen. Load parameters will need to be adjusted accordingly.

7. State if any special handling requirements are necessary due to the design or composition of the pile.

8. List any special techniques or fixtures required to drive the pile.

9. Detail fastening and joining methods especially if certain critical restrictions or limitations apply. If such critical requirements apply, the pile should be so labeled. List and describe any special hardware needs.

10. The materials composition of the pile shall not pose a hazard to the environment through any leaching action.

11. The piles shall have a fire performance rating as required by local use requirements or codes. Reference the National Fire Prevention Association's Standard 307, Construction and Fire Protection of Marine Terminals, Piers, and Wharves for overall system design considerations.

Specification Guide for Sheet Piles

1. Required width dimensions noting upper and lower limits and any shape restrictions.

2. Required total pile section length.

3. EI determined experimentally using ASTM test method (currently under development). Until this method is completed, the test shall be conducted in a four-point bending mode on a full-sized pile specimen with an appropriate L:D ratio. Special test fixturing will be necessary for corrugated sections. A test must also be conducted to show that the connections between two or more sections has properties equal to or greater than the individual section.

4. Flexural creep data as determined on a full-sized pile specimen. Design load parameters will need to be adjusted according to results.

5. State if any special handling requirements are necessary due to the design or composition of the pile.

6. List any special techniques or fixtures required to drive the pile.

7. Detail fastening and anchoring methods especially if certain critical restrictions or limitations apply. If such critical requirements apply, the pile should be so labeled. List and describe any special hardware needs.

8. The materials composition of the pile shall not pose a hazard to the environment through any leaching action.

7 Conclusions, Recommendations, and Discussion

Conclusions

From an overall perspective, the results of the laboratory and field testing performed as part of this study show that FRP composites offer viable alternative choices to the traditional materials for fender, bearing, and sheet piling systems and can provide the engineer with a variety of materials and manufacturing processes that satisfy performance criteria established by the engineer. To the mutual benefit of all those involved, the CPAR Piling Project provided a link between manufacturers interested in developing and marketing composite piling systems and users of piling systems looking for enhanced performance over the traditional systems. While many of the existing composite piling products have shown, through laboratory and field experiences, that they can perform adequately in the service intended, those manufacturers who have made a commitment to this technology are expected to continue to improve and provide future generation composite products that will provide enhanced and more consistent performance properties. Specific conclusions regarding each piling type follow.

Fender

Based on the cold, radial compression tests, some of the composite piles can absorb more than 40 times more energy than a timber pile in those specific modes of loading. This performance represents a distinct advantage over wood for fendering applications especially if the system can withstand repeated loadings (berthings) without major system failure due to cumulative damage.

While the cold radial compression test results were considered valuable to evaluate the response of the pile to that type of loading, the test procedure used in this project may need to be modified for future use to better predict component performance in actual use. This is especially true when the area being compressed would have a hole drilled through it for fastener connection as were the piles installed at Port Newark. The hole would be a stress riser adversely

affecting the results. Another consideration is when walers are placed between the piles (Figure 27) and to what extent the pile could deform before the load of the berthing vessel would be shared by the adjacent walers. A similar consideration is also needed when a fastener is placed at the location of compression. That is, one must consider how much the pile would deform before the vessel would come into contact with the fastener. This demonstrates that — for the results to be most useful — careful thought must be given to which tests are done to determine component performance characteristics, and how those tests are done, since the type and manner of testing definitely relate to the system design specifics.

Accounting for some reduction in the calculated EI (due to the error introduced by using short spans to conduct the tests), four of the five composite fender piles met the bending stiffness requirement. The Trimax fender pile did not meet the minimum requirements for EI. However, the Trimax pile had a diameter of only 10 in. as compared to nominal 13-in. diameters for the other piles. While an increase in diameter would increase the overall EI, it would still likely be less than the minimum as established by the Project Team. The Trimax fender pile is likely to be too flexible to function in a design where bending would be the predominant mode of loading.

Low temperatures had a significant effect on the results of the bending tests of the Trimax and Hardcore DuPont piles. While their method of reinforcement is different, both Trimax and Seaward International use recycled HDPE as the primary matrix polymer material. Yet the Seaward International pile did not show near the same magnitude of change in stiffness at –20 °F as did the Trimax pile. The reason for this difference is not readily obvious. However one possibility is that, while each matrix is still predominantly HDPE, the matrixes differ in percentages of other thermoplastic polymers that have much different thermal-mechanical properties than HDPE. While fracture was the ultimate mode of failure for all of the piles tested at –20 °F, the Trimax pile was the only pile that broke into two completely separate pieces. All of the other piles make use of continuous fibers and/or cloth to provide reinforcement. Even though fracture failure had occurred, there were enough continuous fibers left bridging the fracture gap to hold the major pieces together. The short glass fibers used in the Trimax pile were not able to bridge such a fracture gap and complete separation occurred.

Generically the Hardcore DuPont and the Lancaster Composite piles, as submitted for the bending tests, are similar in that they are both fiber-reinforced polymer composite tubes filled with concrete. However, the composition and the

fabrication methods used to produce the tubes (or stay-in-place-forms) are completely different from each other. Likewise, the concrete formulations used by each manufacturer are also very different. These product differences are likely the reason for the large increase in the stiffness of the Hardcore DuPont pile as compared to the Lancaster Composite pile when decreasing the temperature to –20 °F. One possibility is that, as the composite tube of the Hardcore DuPont pile contracts at low temperatures, the frictional bond between the polymer matrix tube and the concrete is increased. An increase in bending stiffness results. This effect is not seen with the Lancaster Composite pile since they employ an expansive concrete in the manufacturer of their pile, thus providing a high initial frictional bond even at room temperature. In addition, the composite tube used in the Lancaster Composite pile is filament wound, giving a high hoop strength. Due to the orientation of the fiber reinforcements, a filament-wound tube would likely show less shrinkage of tube diameter when the temperature is lowered to –20 °F as compared to a non-filament wound tube as used in the Hardcore DuPont pile.

While the different fender piles installed at Port Newark were driven using a diesel hammer, an instrumented Pile Driving Analysis (PDA) was not conducted. The relationship between EI (bending stiffness) and the ability to easily drive the pile was demonstrated by the Trimax pile. The Trimax pile had the lowest EI value of the piles evaluated and it presented the most difficulty in driving.

As demonstrated by the cracking of the piles at the Port Newark demonstration, fastening methods with these composite piling systems requires special attention. Methods of fastening must be developed for each type piling as optimum techniques could vary significantly based on material composition and structure of the pile.

Loadbearing

Of the four loadbearing piles tested, only Creative Pultrusions' pile failed to meet the minimum load capacity as set forth in the Performance Target Goals. Although it met the minimum established load capacity requirements, the Hardcore DuPont pile failed at a lower load capacity than expected given its concrete fill. The upper limit for the Seaward International and Lancaster Composite piles was not determined as they exceeded the capacity of the test machine.

While the test results to compute EI indicate that all of the piles should be drivable, no driving tests and PDA were performed as part of this CPAR project.

Hardcore DuPont and Lancaster Composite have had PDAs performed on their piles. Creative Pultrusions and Seaward International have demonstrated the ability to drive their piles through actual pile installations (e.g., Port Newark and Tiffany Street).

Issues of creep were not resolved as part of the project. Based on material compositions and the results of the compression tests (including the results at the different stain rates), it is estimated that the piles would qualitatively rank from those piles where creep would be of greatest concern to least concern as follows: Seaward International > Creative Pultrusions > Hardcore DuPont > Lancaster Composite. Virtually all materials exhibit creep under sustained high loading. Below some threshold value, creep may be negligible (this being the maximum loading the material would normally be subjected to ensure a reasonable life of the structure) and above that value, creep may be very rapid, resulting in catastrophic failure. Temperature is also a primary influence factor in the rate of creep. The higher the temperature, the greater the rate of creep. A change in temperature would be expected to have a more pronounced effect on the rate of creep of the Seaward International pile with its HDPE matrix than the piles made by Creative Pultrusions, Hardcore DuPont, or Lancaster Composite with their thermoset resin matrix.

Sheet Piling

Special test fixturing must be fabricated and used to most accurately measure the flexural properties of the corrugated sheet piling components.

Creative Pultrusions, International Grating, and Trimax all have “standard” products that met the “very light-duty” category of the sheet pile Performance Target Goals. No composite sheet pile product was developed that met the performance requirements for a heavy-duty steel sheet pile such as PZ-27.

Based on the promising results of the honeycomb sheet pile sections, the use of “composite” construction (e.g., concrete-filled shells or “stay-in-place” forms) may offer the means to produce a heavy-duty, nonmetallic sheet pile system.

Recommendations

The following recommendations are presented separately for each class of piling.

Fender Piles

Due to variations in material composition and design, each of the fender piles developed and/or evaluated as part of this CPAR project has its own unique properties. Given appropriate considerations in the design of the structure, any of these composite piles can be used as a fender pile. Some of the considerations include: (1) the size of the vessels being berthed, (2) the geometry of the pier structure and whether the mode of loading is more or less in a radial compression (pinch) mode or a bending mode, (3) average temperature and expected temperature extremes, and (4) the use or absence of camels (which spread the load over several piles) as well as other auxiliary bumpers. The structural design engineer is then responsible to select the fender pile type and design that will best work with the structure, considering total structure function, performance, and project budgets.

The performance of the installation at Port Newark should be monitored by the industry over the next 10 to 15 years, at minimum. Technical reports or papers should be composed by the Composites Institute at 5-year intervals and submitted to the literature. Since their piles were not included in the Port Newark demonstration site, installation of Hardcore DuPont and Lancaster Composite fender piles should also be documented by the Composites Institute or other third party group and submitted to the literature.

To minimize the occurrence of failures at connection points, each manufacturer must be able to provide guidance regarding appropriate and inappropriate connection details for their piles. Special hardware must be designed and provided if necessary for optimum pile performance.

As with Creative Pultrusions' pile, Hardcore DuPont's and Lancaster Composite's fender piles should incorporate a replaceable wear or rubbing surface such as a high-density polyethylene (HDPE) or ultra-high molecular weight polyethylene (UHDWPE) skin or wrap. Without such protection, the composite skin is likely to see accelerated wear as the berthing vessel oscillates up and down through wave action.

Shipping restrictions can limit the length that a pile can be when transported from the manufacturer's plant to the point of use. Piles of 100 ft in length or more may be required for some applications. For those manufacturers not capable of fabricating such long piles as continuous sections or where shipping restrictions limit the total pile length that can be shipped, splicing techniques

will need to be developed. Of course, the overall mechanical properties must not be compromised by this connection joint.

Standardized test methods need to be developed and adopted by ASTM to measure and evaluate radial compression, flexural properties, and wear resistance (due to rubbing of the vessel against the pile face). The effects of low temperature on system performance must also be included. Product specifications should be developed for each type piling system and adopted by the most appropriate industry consensus standards group e.g., ASTM and the American Concrete Institute (ACI).

During the course of the project, suggestions were made by the Project Team to optimize the design of some of the manufacturers' systems. Generally these suggestions focused on changes in geometry, and on placing higher strength materials or more materials in areas of higher stress. The high cost of making new dies and initiating new processing changes discouraged the incorporation of these suggestions into this project. The change in shape could even negatively affect user and/or installer acceptance of the product because the item would appear so different from what they are used to. However, it is hoped and expected that, as composite fender piles find increased market acceptance, the manufacturers will consider the above suggested geometry enhancements.

Loadbearing Piles

As with the fender piles, each of the loadbearing piles developed and/or tested as part of this CPAR project has its own unique properties. Given appropriate considerations in the design and function of the structure, any of these composite piles can be used as a loadbearing pile (column). A major consideration is the expected structural loading (live load and dead load) and the probability of buckling because of long slender columns as is with any traditional materials. The loadbearing capacity of the piles tested under this project ranges from less than a standard timber pile to an unknown upper limit much greater than a timber pile. The structural design engineer must be responsible to develop appropriate system designs based on the type pile to be used. Since creep and flexural stiffness are not very well documented for these piles, appropriate large factors of safety should be applied until performance history is documented and/or further laboratory and field tests are completed that justify a reduction in the factor of safety.

While no tests were specifically performed to determine the effect, some concern was raised regarding the use of hollow pile sections, such as Creative

Pultrusions' tic-tac-toe profile, in locations where water may infiltrate into the middle core section and undergo freeze/thaw cycles. To alleviate such concerns, the hollow core could be filled with concrete or some other impervious material. In fact, the effect of filling the hollow core of the Creative Pultrusions' tic-tac-toe pile with concrete should be evaluated from a mechanical performance and economic perspective.

Creep and buckling issues must be appropriately addressed and understood prior to the use of these piles in any large, critical loadbearing applications.

Due to the importance of such interactions in loadbearing applications, new studies need to investigate composite pile-to-soil interactions.

FRP composite piles not only have the potential of replacing wood piles but reinforced concrete piles as well. However, to gain acceptance for such structural applications, a history of performance will be necessary. Therefore, as the member manufacturers gain opportunities to install loadbearing piles, the Composites Institute should help document these applications and publish information on their performance and design.

Standardized test methods need to be developed to determine flexural properties, which are important in evaluating column buckling in loadbearing applications. Product specifications should be developed for each type of piling system and adopted by appropriate industry consensus standards group, e.g., ASTM and the American Concrete Institute (ACI).

The issue of fire performance needs to be further addressed, especially for loadbearing piles. More data needs to be generated relative to the performance of composite piles in various fire scenarios, e.g., performance of the pile (and system) in a pool fire (i.e., burning liquid on the surface of the water). ASTM Committee Section D20.20.04 is planning to address some of these fire issues to develop an understanding and consensus agreement among users, owners, and regulators. Fire resistant resins, such as phenolics or fire-retardant additives can be incorporated into a composite pile for the pile to meet the needed requirements.

Sheet Piling

The three different composite sheet pile products evaluated as part of this CPAR project can be classified as two basic types: (1) tongue-and-groove recycled plastic timbers reinforced with chopped glass fibers, and (2) glass fiber-reinforced

pultruded profiles. Given the performance properties of all three of these sheet pile products, applications are currently best suited for light-duty applications such as marinas and shore line protection along a river or lake front.

Continued development of FRP composite sheet piling for more heavy-duty applications is encouraged. The use of composite structures (that is, FRP composites along with concrete) may provide the increased bending stiffness needed for the more heavy-duty applications. The use of plastic lumber walers and FRP composite tie-backs also needs to be investigated. Some of this work is being included in a new project on FRP Composite Gates and Sheet Piles under a newly started Corps of Engineers' Program on High-Performance Materials and Systems.

Some preliminary studies initiated at USACRREL (Dutta and Sodhi 1998) have shown that ice could cause serious damage to the pultruded composite sheet piling, especially at sharp corners. The effects of ice impact and rubbing need to be further assessed.

As promising new high-performance, heavy-duty, composite sheet piling systems are developed, they should be installed in a controlled, full-scale field demonstration test. The system should be instrumented for long-term monitoring and evaluation.

Since sheet piling is usually subjected to long-term bending stresses, flexural creep is a critical property that must be investigated.

Standardized test methods need to be developed and adopted by ASTM to measure flexural properties and creep. The effects of low and high temperatures on system performance must be considered. As described above for loadbearing piles, the issue of fire performance for sheeting piling also needs to be further investigated.

Discussion

The CPAR Piling Project was organized in such a way that it focused on the application of existing FRP composites technology for new end-use products such as bearing piles, fender piles, and sheet piles (bulkheading). The Project developers recognized a need for more durable, cost-effective products to combat the problems of marine wood borer attack of creosote-treated timber piles, and corrosion of steel piles and steel-reinforced concrete products. FRP composites

had been used successfully in the salt water and fresh water operating environment in pleasure craft, commercial fishing vessels, and military ships. The material had an excellent track record of durability and strength. It was, therefore, the intent of the CPAR Project Partners to apply the industry knowledge of FRP composite materials in marine service to the specific problems of marine piling in its various forms. The CPAR Piling Project was never intended as a long-term research project, but was rather designed as a unique opportunity for the FRP composites industry to respond to a new market opportunity within the Corps and waterfront industry with primarily off-the-shelf or short-term technology development. The Industry Partner believes this to be the best and most efficient use of project resources.

During Phase One of the CPAR Piling Project, industrial manufacturers were encouraged to submit candidate products or conceptual designs for lab-scale evaluation. Most of the products or conceptual designs that were proposed by industry were actually adapted from other products (e.g., Shakespeare proposed a filament-wound tapered pile based on their commercially successful lighting pole design; Specialty Plastics modified an existing design for radar-transparent non-structural pilings that the company was already selling to the U.S. Navy; Lancaster Composite modified a design for industrial fence posts; Creative Pultrusions proposed an alternative use of a proven structural profile from the cooling tower industry; etc.). Others such as Seaward International and International Grating already had first generation products in the marketplace. This project allowed these companies to optimize their products for specific environments determined critical by the end-user. Testing existing products shortened the lead time to develop products from the beginning. This project also allowed the industry to participate and support the Corps in a timely fashion.

Another deliverable is perhaps as valuable as any technical findings: this CPAR Piling Project provided a forum in which manufacturers could exchange ideas, undertake meaningful dialog with the end-user or practitioner community, and begin the process of subsequent design optimization — something that is apparent among many of the project participants even today. At the recent Ports '98 Conference in Long Beach, CA, the Composites Institute Market Development Alliance (MDA) exhibit of waterfront products coupled with individual exhibits of five product manufacturers showed the extraordinary upsurge in product availability and customer interest. Arguably, this would never have happened without the unifying influence of this CPAR Piling Project.

In summary, the CPAR Piling Project should be viewed as having accomplished a technology facilitating function as opposed to development of a new technology. In addition, as a result of this CPAR Project, manufacturers began to view the marine/waterfront environment as fertile ground for a variety of other, non-piling products including concrete reinforcement, decking systems, coatings, repair systems, pier utilities, etc. This expansion of FRP composite technology to marine/waterfront applications is based on the recognition that the same beneficial characteristics that composites bring to marine/waterfront piling applications would provide performance improvements in other, non-piling products made from FRP composites. As noted in the Commercialization/ Technology Plan, piling manufacturers are establishing a new Composite Piling Manufacturers' Council under the auspices of the Composites Institute. This new council will undertake the classic activities of a trade association, including gathering industry statistics, developing specifications and standards (to be promulgated by a recognized marine/waterfront specification body), and undertaking industry-level communications.

8 Commercialization and Technology Transfer Plan

Background

One of the objectives of the FRP Composite Piling CPAR project was to establish and put into operation technology transfer capabilities designed to accelerate practitioner acceptance in the marine/waterfront industry while shortening the time-to-market for these new products.

The FRP Composite Piling CPAR CRDA gave primary responsibility for technology transfer and commercialization to the Composites Institute and its member companies. As the composites industry's leading organization, the Composites Institute's Market Development Alliance (MDA) has developed a unique pre-commercialization technology transfer model to successfully address this project need. The MDA technology transfer model provides crosscutting mechanisms and provides for collaboration with key, end-use industry organizations to accelerate the steps required to demonstrate and commercialize new FRP composite products. This section of the report outlines a recommended strategy to expedite technology transfer for FRP composite pilings in the marine/waterfront segment of the United States civil engineering industry while minimizing requirements to create or invest incremental hard assets on the part of the developing organizations.

Commercialization/Technology Transfer Plan

The commercialization/technology transfer plan assumes that the technology need is for FRP composite piling products in the United States only. However, the CPAR project participants clearly recognize that a much larger international opportunity exists for these new products.

The long-term commercialization/technology transfer needs of the project will require some form of sustaining industry organization be established (e.g., an "FRP Composites Piling Products Council" or equivalent organization) to carry

out those portions of the technology transfer plan that extend beyond the completion date of the CPAR project itself.

The major steps associated with technology transfer for FRP composite piling include:

- establishing a new industry-based organization to carry out the technology transfer plan recommendations
- creating an Advisory Board to help guide the new FRP Composites Piling Council in its activities
- developing an industry guide to design, construction practices, installation, repair, etc.
- publishing technical articles and product performance case histories in key industry publications
- conducting outreach and practitioner education activities including exhibits at key industry events, continuing demonstration projects at the regional level of the industry, and offering seminars through leading marine/ waterfront industry organizations.

CPAR Project Technology Transfer Deliverables

The FRP Composite Piling CPAR project technology transfer plan addressed and completed the following steps.

1. *Technology Transfer Advisory Board.* The purpose of the Technology Transfer Advisory Board was to bring the "reality" of the marketplace into the development process at a stage that was early enough to influence significant technical and commercial decisions. The FRP Composite Piling Products CPAR Advisory Board was intended to comprise marine architects, designers, structural engineers, contractors, owner/operators of port and waterfront facilities, and all key trade-technical-and-professional organizations (TTPOs), code bodies, regulatory organizations, and others with a "stake" in the application of this technology. The role of the Advisory Board was to continually provide the CPAR team, and potentially any successor organization(s) with the following critical information:

a. Characterize traditional materials and construction practices

- strengths
- weaknesses
- needs
- industry influence factors

b. Establish performance and installed cost targets

c. Identify approval authorities

- TTPOs
- standards promulgating bodies
- codes
- regulatory approvals

d. Recommend and coordinate continuing demonstration projects

e. Provide liaison to key industry organizations

f. Act as technology advocates within their respective communities.

A total of five ports owner/operators and five engineering or TTPOs were contacted and agreed to serve on an FRP composites piling advisory board.

2. *Survey of Piling Manufacturers*. A survey of manufacturers of FRP composite piling was conducted. The majority of manufacturers responded positively to create such an organization. This is expected to provide the nucleus for the establishment of a permanent industry organization.

3. *Technical Sessions at Key Waterfront Industry Events.* The Market Development Alliance organized and conducted FRP composite piling technical sessions at 1997 PIANC annual conference and at ASCE PORTS '98, the largest waterfront event in the Western Hemisphere (Lampo et al. 1998). In addition, the MDA orchestrated a very successful exhibit of FRP piling and related waterfront products at both ASCE PORTS '95 and '98. Leads generated from

these technical sessions and exhibits were distributed to manufacturers for follow-up.

4. *ASTM Technical Committee.* A new ASTM Committee Section, D20.20.04, concerning Systems for Marine and Waterfront Applications was established to develop material specifications, performance criteria, and test methods for the composite piling systems such as those being developed under this CPAR Project. The initial meeting of this Section occurred in Salt Lake City, UT, on 23 July 1996. Task Groups are currently active for Fender Piles and for Sheet Piles. The current focus of the Section is on testing methods to determine flexural and radial compression properties of fender piles as well as specifications for fender piles and bulkheading systems. The Section meets three times a year (spring, summer, and fall) with the rest of Committee D20. Information on meeting schedules and locations can be obtained from ASTM Headquarters at 100 Barr Harbor Drive, West Conshohocken, PA 19428. The issue of combustibility has been a major topic of discussion at past meetings. A special meeting on this topic was held at the Underwriters Laboratory in Northbrook, IL, during June of 1997.

Future Technology Transfer Activities

Developing Preliminary Standards and Handbooks of Practice

A critical technology transfer step is the development of construction documentation (design protocols, means and methods, etc.), preliminary specifications and standards that establish minimum industry practice, and lead to approval of the developed products. By and large, the U.S. marine/waterfront construction community has no widely recognized approval mechanism to accomplish this. The American Society of Civil Engineers (ASCE) has some standards and guide document oversight through its Ports, Harbors, and Waterways Sub-Committee structure. However, it has been several years since ASCE was active in such standards writing. The Permanent International Organization of Navigational Congresses (PIANC) is also a conduit for information, but lacks standards-making capabilities in the United States. The American Association of Ports Authorities (AAPA) is a market facilitator, but does not undertake standards making.

One possibility is to approach the Civil Engineering Research Foundation's new Civil Engineering Innovative Technology Evaluation Center (CE-ITEC) to design an evaluation and testing plan for the piles being developed and evaluated under

the CPAR piling project. It should be expected that feedback from the CE-ITEC would identify areas for product improvement, modifications required, or other fine-tuning that will require an iterative loop back into the research and/or development phase. This will be outside of the timing and scope of the current CPAR project. Assuming that the evaluation process validates the product, the next step is widespread, but focused demonstration to the prospective market.

At the minimum, a technical "package" comprising the following information should be prepared for practitioners by the Piling Manufacturers' Council members:

1. General background on FRP composites.

2. An illustrated history of the FRP composite piling CPAR project.

3. Handbook of industry construction practices for FRP composite piling systems. This should contain recommendations on handling, storage, installation, connections, maintenance, repair, and technical support.

4. Manufacturers literature and technical information.

5. Summary of "expert" resources (consultants, universities, TTPOs, etc.).

Creating such essential documentation should be undertaken through cooperation between all interested FRP composites piling industry manufacturers in a new FRP Composite Piling Council under the Composites Institute.

Continuing Demonstrations

Demonstrations should be conducted on regional and local bases and, in all cases, coordinated through industry events including knowledgeable waterfront industry organizations (AAPA, ASCE, PIANC, etc.). Generally speaking, the number of field demonstrations of the technology will be directly proportional to the size and fragmentation of the target market. It is essential that relationships with key industry publications be established during this phase of the project. For the purposes of the FRP Composites Piling CPAR, regional demonstrations should be organized in conjunction with the Advisory Board and participating trade, technical, or professional organizations. In addition, the U.S. Army Corps of Engineers, U.S. Navy, and U.S. Coast Guard should each determine the minimum number of service branch-specific demonstrations sufficient to satisfy their particular needs.

Continuing Promotion and Publicity

The project team recognizes the need for an aggressive promotional and publicity plan. Working in concert with the Advisory Board, promotional and publicity efforts should be targeted on industry media and key TTPOs. Specific recommendations include articles in ASCE, *Pile Buck* Magazine, and other publications that serve the marine/waterfront engineering community. Whenever possible, demonstration sites should be used as promotional vehicles for chapters of local TTPOs and tours provided to such organizations.

Continuing Education and Training

A new continuing education and training "package" should be developed to introduce the new FRP Composites Piling technology to marine/waterfront practitioners. This package should be created in association with the key trade and professional organizations of the marine/waterfront industry. These educational packages should also be widely publicized through the industry media. Educational packages should include all information (per article 2.1 through 2.5 [above]) plus video and slide presentations. A web site for this project should be created by the Composites Institute to allow access to composites industry information. Other exhibits and demonstrations should take place at key TTPO venues. Technical papers should be written and presented at every major end-user industry event (Lampo et al. 1997; 1998).

Training materials should be made available to all qualified engineering colleges and universities through appropriate channels, for example the American Society of Civil Engineers Student Chapters organization.

Continuing Commercial Proliferation

The above steps are the essential elements of a post-CPAR, full-scale commercial launch. The recommended implementing steps include exhibits at industry trade shows, continuing demonstrations at national, regional, and local levels. The mainstream activities of key industry TTPOs should be integrated in the sequence listed so as to create a "domino" effect. In all cases, the process seeks to integrate FRP composites development into the mainstream of the existing industry structure using the resources and contacts of the U.S. marine/ waterfront civil engineering community.

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CEGS 02360 Steel H-Piles Jan 89

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CEGS 02362 Prestressed Concrete Piling Feb 89

CEGS 02363 Cast-In-Place Concrete Piles, Steel Casing Feb 89

CEGS 02365 Piling, Composite: Wood & Cast-In-Place Concrete Jul 89

CEGS 02383 Drilled Foundation Caissons (Piers) Apr 89

CEGS 02371 Auger-Placed Grout Piles Jul 89

CWGS 02311 Round Timber Piles for Hydraulic Structures Oct 95

CWGS 02315 Steel H Piles May 93

CWGS 02365 Prestressed Concrete Piles Nov 94

CWGS 02411 Metal Steel Piling May 92

Corps Of Engineers Engineering Manuals

EM 1110-1-1905 Bearing Capacity of Soils Oct 92

EM 1110-2-1204 Environmental Engineering for Coastal Protection Jul 89

EM 1110-2-1612 Ice Engineering Oct 82

EM 1110-2-1614 Design of Coastal Revetments, Seawalls and Bulkheads Apr 85

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EM 1110-2-2502 Retaining and Flood Walls Sep 89

EM 1110-2-2503 Design of Sheet Pile Cellular Structures Sep 89

EM 1110-2-2504 Design of Sheet Pile Walls Mar 94

EM 1110-2-2602 Planning and Design of Navigation Lock Walls and Appurtenances, June 60

EM 1110-2-2904 Design of Breakwaters and Jetties Aug 86

EM 1110-2-2906 Design of Pile Foundations Jan 91

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EM 1130-2-303 Breakwaters, Piers, Jetties and Similar Structures Dec 67

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Military Specifications

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Military Handbook

MIL-HDBK 1025/1, Piers and Wharfs

MIL-HDBK 1025/6, General Criteria for Waterfront Construction

Other Publications

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Appendix A:Construction Productivity Advancement Research (CPAR) Program

The Construction Productivity Advancement Research (CPAR) Program was a cost-shared research and development (R&D) partnership between the U.S. Army Corps of Engineers (USACE) and the U.S. construction industry (e.g., contractors, equipment and material suppliers, architects, engineers, financial organizations, etc.). In addition, academic institutions, public and private foundations, nonprofit organizations, state and local governments, and other entities interested in construction productivity and competitiveness also participated in this program. CPAR was created by the Secretary of the Army to help the domestic construction industry improve productivity and regain its competitive edge nationally and internationally. This was to be accomplished by enhancing USACE construction R&D programs with cost-shared industry partnerships. The objective of CPAR was to facilitate productivity-improving research, development, and application of advanced technologies through cooperative R&D programs, field demonstrations, licensing agreements, and other means of technology transfer. The CPAR Program was discontinued after FY96.

The Federal Government is the largest single buyer of construction services. Technology advancements that improve construction productivity will reduce construction program costs. Projects not now economically feasible may become feasible due to lower construction costs. Such cost savings would accrue directly to the Federal Government's construction program, and would benefit the U.S. construction industry and the U.S. economy in general.

CPAR was intended to promote and assist in the advancement of ideas and technologies that would have a direct positive impact on construction productivity, project costs, and USACE mission accomplishments. R&D and technology transfer under CPAR was based on proposals received from educational institutions, the construction industry, and others that would benefit both the construction industry and the Corps of Engineers. The CPAR Program permitted USACE to act on ideas received from industry, to cost-share partnership arrangements, and to rapidly implement successful research results

through aggressive technology transfer and marketing actions. Section 7 of the Water Resources Development Act of 1988 (P.L. 100-676) and the Stevenson-Wydler Technology Innovation Act of 1980, as amended (15 U.S.C. 3710a et sea.) provided the legislative authority for the CPAR Program.

Appendix B: Composites Institute's Piling Design Competition

composites

MARKET DEVELOPMENT ANNOUNCEMENT

Next Generation Composite Pile Design/Fabrication Competition

Executive Summary

The Composites Institute's Market Development Alliance Marine/Waterfront Task Group and the Composite Piling CPAR Team is pleased to announce an industrial design and fabrication competition called *"Next Generation Composite Pile Design/Fabrication Competition."*

The objective of this competition is to develop innovative designs for high-performance polymer composite fender pilings, bearing pilings, and sheet pile (bulkheads) for marine/waterfront applications. Composite piling products selected for development during this competition will be analyzed and tested. Products with the best potential for meeting the established performance criteria will be installed at selected demonstration sites.

Project Background

The Composites Institute entered into a Cooperative Research and Development Agreement (CRDA) with the U. S. Army Corps of Engineers and Rutgers University under the Corps' Construction Productivity Advancement Research (CPAR) Program. The objective of this CPAR project is *to develop and demonstrate high-performance polymer composite fender pilings, bearing pilings, and sheet pile (bulkheads) for marine/waterfront civil engineering structures.* The enclosed Project Fact Sheet (see Attachment A) provides a brief overview of the project. The CPAR project team, comprised of the Corps, academia, composites industry, designers, and end-users, have identified performance criteria that defines the dimensional, mechanical, environmental, operating, installation, jobsite, and cost parameters that piling systems must satisfy to replace traditional materials. Additional goals of this project are to demonstrate cost-effective and technically superior pile systems, initiate the technology transfer of this information into codes and standards, and to achieve wide-spread commercial acceptance of composite piling products in the marine/waterfront industry.

The Product

The products to be developed are fender piles, bearing piles, and sheet piles (bulkheading). An explanation of each pile function is shown in Attachment B. The piles shall be constructed from a matrix

of polymeric material reinforced by fibers or other reinforcement with a discernable aspect ratio of length to thickness sufficient to produce a reinforcing function. All composite manufacturing processes and materials will be considered for the products submitted for this competition. Product designs shall be developed to meet the performance targets goals shown in Attachment C. Participants can submit a product design for any or all categories of piles.

Why Composite Piles?

Traditional piling and sheet pile materials are inherently unsuited to harsh waterfront environments. Pressure-treated timber pilings are subject to attack by marine organisms and pose disposal problems when being replaced. Steel-reinforced concrete pile and sheet pile can fail due to chloride ion attack and freeze/thaw degradation. The problems of corrosion on steel piling and sheet pile are well documented. According to the U. S. Navy, deterioration of wood, concrete, and steel piling and sheet pile costs the military and civilian marine/waterfront civil engineering community nearly $2 billion annually.

Such traditional practices as pressure treatment of lumber or sandblasting and solvent/lead-based painting of steel are potentially harmful to the environment. Properly designed and manufactured composite piling and sheet pile should be superior to traditional materials in marine operating environments. The U.S. construction industry lacks the understanding and sufficient confidence in the design and long-term performance of composite products in civil engineering structures. Composites are already used in load-bearing civil engineering structures for the chemical processing, oil and gas, and water/wastewater industries. By transferring this technology to wide-spread use in marine/waterfront civil engineering structures, U.S. ports, harbors, and waterways operators can save millions of dollars every year. The resulting products and technology can be exported or licensed to international markets, thereby offering further benefits to U. S. industry.

Who Should Participate?

This competition is open to any member in good standing of the SPI/Composites Institute who possesses the capability to design and/or fabricate polymer composite structures. New members are welcomed to participate in this competition. Currently available commercial products may be submitted for validation via the design competition. Existing business in the marine/waterfront markets is not a prerequisite for this competition. Experienced member designers, fabricators, and their materials suppliers can propose any number of new and innovative piling design concepts. "Teaming" between fabricators and material suppliers is strongly encouraged to increase the chances for successful proposals. CI staff can provide assistance in forming teams of interested parties.

Benefits of Participation

The intent of this CPAR project is to develop and make commercially available to the marine construction industry innovative composite piling systems to replace such systems currently made from traditional materials. CI members who submit candidate piling designs will receive recognition for their participation. Their designs will be evaluated by a team of industry experts for technical suitability as well as commercial viability at no cost to the proposer. Successful designs will be prototyped, tested, and, if

successful, will be showcased in a series of high-visibility demonstration projects.

Any proprietary information that is made available to CPAR Team members as part of this project will be held in the strictest of confidence and not further disclosed to third parties without prior consent of the owner. Patentable designs and information developed as part of this design competition and CPAR project will remain the property of the originator(s). Specific details on intellectual property rights will be addressed on a case-by-case basis. The intent is to encourage, not to discourage, the development and commercialization of innovative composite material technologies for use by the construction industry.

Competition Overview

Phase I:	Submit design proposals.
Phase II:	Prototype and laboratory testing.
Phase III:	Full-scale fabrication, testing, and demonstration of candidate products.
Phase IV:	Product technology transfer and commercialization.

Deadline Dates

a) August 2, 1995	Response to participate in the competition.
b) October 2, 1995	Phase I: Submittal of proposed designs.
c) October 23, 1995	Selection of successful designs.
d) November 1995 - April 1996	Phase II and III: Completion of coupon and prototype samples, completion of full-scale samples, and execution of the test program.
e) Summer 1996 - Summer 1997	Phase III and IV: Demonstration projects.

Response/Inquiry

To participate in this competition or to obtain additional information, please fax the attached response form or contact John P. Busel, Composites Institute, (212) 351-5413. Submit proposals to: John P. Busel, Manager, Market Development, Composites Institute, 355 Lexington Ave., New York, NY 10017

Judging Process

The test samples will be judged based on meeting the performance target goals as shown in Attachment C. Representatives from the U.S. Army Corps of Engineers and Rutgers University will officiate.

The CPAR Team will offer a telephone debriefing to unsuccessful proposers. We recommend that you take advantage of this debriefing to hear the judging panels's views regarding the strengths and weaknesses of your piling design proposal. This feedback can help proposers to better address factors considered weak in the original proposal and possibly re-submit a revised or improved design.

Participation in Phase II, III, and IV requires membership in the Composites Institute Market Development Alliance (MDA). For a prospectus and details on joining the MDA, contact John P. Busel at (212) 351-5413.

Test Program

The testing of selected samples is shown in Attachment D. Specific tests are outlined for the different pile categories. The samples will be tested by the participant organizations in the CPAR project. If your proposed design is accepted, you will receive shipping instructions to send the product samples to the respective laboratory/test facility. If you have any questions or need additional information contact Dr. Tom Nosker, Rutgers University, (908) 445-3632.

Project Team Support for the Competition:

Support teams have been organized to assist in preparing and submitting your design(s). The teams will:

- provide support for analysis and ranking of proposed designs
- provide support during product fabrication
- coordinate lab-scale and full-scale testing of proposed designs

The point of contact for the support teams are:

- **Fender Pile and Bearing Pile** - Rich Lampo, U.S. Army Corps of Engineers Construction Engineering Research Laboratory, (800) USACERL, ext 6765

- **Sheet Pile** - Dr. Ali Maher, Rutgers University, Dept. of Civil Engineering, (908) 445-2485

For further information on this competition, the Market Development Alliance, or the CPAR Project, please contact John P. Busel, Manager, Market Development, Composites Institute, 355 Lexington Ave., New York, NY 10017; (212) 351-5413 or fax (212) 370-1731.

PLEASE COMPLETE AND RETURN BY WEDNESDAY, AUGUST 2, 1995 TO:

John P. Busel, Manager, Market Development
Composites Institute
355 Lexington Avenue
New York, NY 10017
FAX: 212-370-1731

COMPOSITES INSTITUTE

Next Generation Composite Pile Design/Fabrication Competition

[ ] I will participate in the design competition. Please add my name below as point-of-contact.

I plan to submit design proposals on:

[ ] Fender Pile

[ ] Bearing Pile

[ ] Sheet Pile

(please print)

NAME:____

COMPANY:____

ADDRESS:____

PHONE:____________________ FAX:____________________

Attachment A

PROJECT FACT SHEET

MARINE/WATERFRONT TASK GROUP (MWTG)
CONSTRUCTION PRODUCTIVITY ADVANCEMENT RESEARCH (CPAR)

"COMPOSITE PILING SYSTEMS"

1) **TITLE:** Development and Demonstration of Polymer Composite Pilings and Sheet Pile Systems.

2) **OBJECTIVE:**
To develop and demonstrate high-performance, polymer composite fender pilings, bearing pilings, and sheet pile (bulkhead) systems for marine/waterfront civil engineering structures.
Product: The products to be demonstrated will be fender, structural/bearing piling, and sheet pile systems for marine/waterfront applications. Material standards, specifications, and design guidance will be developed for each type of pile system.

3) **TECHNOLOGY CHALLENGE:**
Traditional piling and sheet pile materials are inherently unsuited to harsh waterfront environments. Chemically treated timber pilings are subject to environmental regulation. Also, timber pilings are subject to attack by marine organisms because harbor waters are becoming clean. Steel reinforced concrete piling and sheet pile can fail due to chloride ion attack and freeze/thaw degradation. Deterioration of wood, concrete, and steel piling systems is estimated to cost the military and civilian marine/waterfront civil engineering community nearly $2 billion annually. Properly designed and manufactured polymer composite pile systems should have superior performance to traditional materials while being cost effective.

4) **START DATE/DURATION:** April 1994/ 3 years

5) **PROJECT FUNDING:**

• USACERL Share:	$800K
• PARTNER Share:	$1,933K ($1,650K Composites Institute contribution)
TOTAL:	$2,733K

NOTE: The Composites Institute funding is provided by the members of MWTG through in-kind services.

6) **PROJECT PARTNERS:**
- U.S. Army Construction Engineering Research Laboratory (USACERL)
- Rutgers University

7) **PARTNER PARTICIPANTS:**
- SPI/Composites Institute
- New York/New Jersey Port Authority

8) **USACERL LABORATORY PARTICIPANTS:**
- U.S. Army Waterways Experiment Station (USAWES)
- U.S. Army Cold Regions Research Laboratory (USACRREL)
- Naval Facilities Engineering Service Center (NFESC)

9) **CI/MWTG PROJECT LEADER:** Robert Taylor, Seaward International

10) **CURRENT COMPOSITES INSTITUTE PARTICIPATING MEMBERS:**

SUPPLIERS:	FABRICATORS:	OTHERS:
• Ashland Chemical	• Creative Pultrusions	• Britt Engineering
• Interplastic Corporation	• International Grating	
• PPG Industries	• Seaward International	
• Reichhold Chemical		
• Owens-Corning		
• Vetrotex CertainTeed		

11) **WORK TASKS ACCOMPLISHED TO DATE (6/95):**
a) Compiled performance design guidance for piling and sheet pile systems including physical, mechanical, operating, and installation requirements.
b) Completed survey of existing piling systems for market use and cost targets.

12) **PLANNED FY 95 WORK TASKS:**
a) Prepare preliminary designs to meet established performance goals. This includes CAD modeling of candidate designs. Performance/design deficiencies compared to performance goals will also be identified.
b) Obtain/fabricate test specimens and conduct laboratory testing on components.
c) Initiate plan for commercialization of products and technology transfer issues. This includes the organization of an advisory board and development of design and construction standards and specifications.

13) **PROJECT NEEDS:**

Key: Most urgent need: XXX	Urgent need: XX	Less urgent need: X
a) Materials Engineering:	X	
b) Structural Engineering/Analysis:	XX	
c) Design	XXX	
d) Manufacturing Engineering:	X	
e) Testing:	XX	
f) Prototype Fabrication:	XXX	

For more project information or to join the Market Development Alliance/MWTG and this project team, contact John P. Busel, Manager, Market Development at (212) 351-5413 or fax (212) 370-1731.

Attachment B

MARINE/WATERFRONT PILINGS
(a primer)

Bearing Pile

Bearing piles comprise those members of a waterfront structure which support their own weight plus that of other parts of the structure. The most common example is a warf (pier). Please see Figure 1. for details.

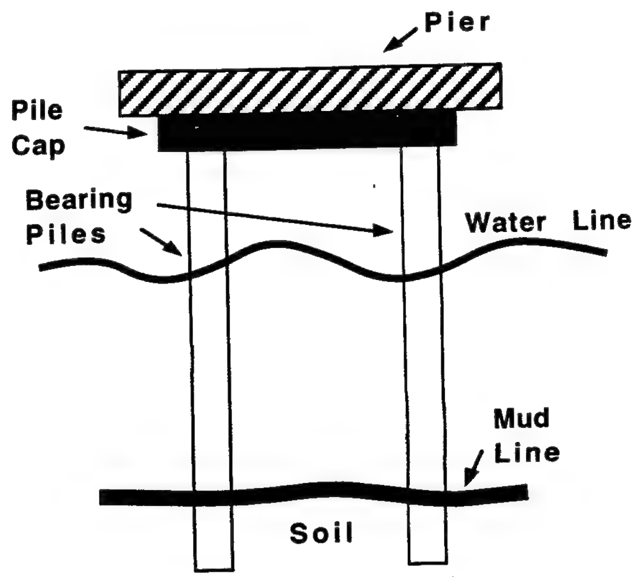

Fig. 1. Typical Bearing Piling

Bearing piles are driven into the mud or soil under the water by several methods including impact (drop) hammers, vibratory hammers, or jetting. Piles that support weight primarily on their ends are known as "end-bearing" piles, while piles that are supported by friction resistance of the surrounding soils are called "friction" piles.

Creosote-treated timber is the most popular piling, followed by steel-reinforced concrete and all-steel piling. Traditional pilings suffer from severe deterioriation from a variety of mechanisms including marine wood borers (Toredo worms), corrosion, and freeze-thaw cycles.

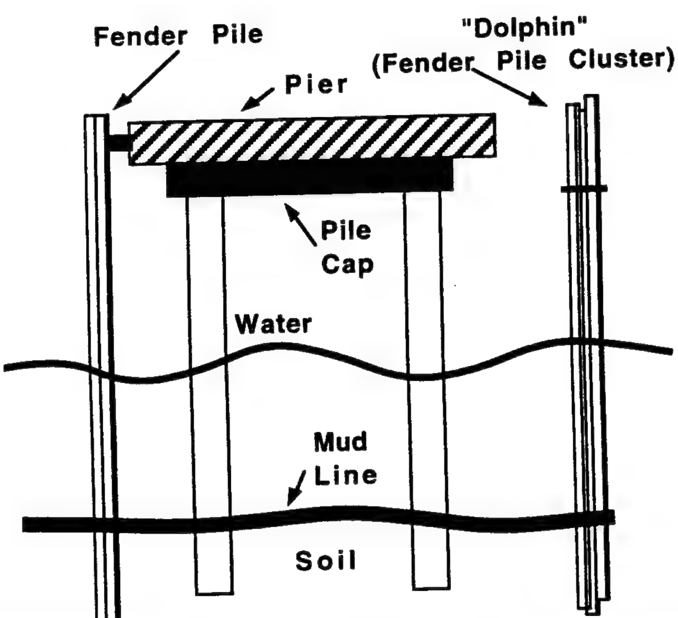

Fig. 2. Fender Piling

Fender Piles

Fender piles are a vital part of the waterfront structure that protects or "fenders" the pier (and the ship) from the berthing energies of approaching ships. If moving ships directly contact a pier, all of the energy of the ship slams into the immovable pier, causing damage to both.

Fenders absorb the berthing energy by bending or otherwise deflecting until the ship is stopped without touching the pier. See Figure 2. Creosote-treated wood is the most popular fender pile. However, this product suffers structural deterioriation with repeated impact and is subject to agressive attack by marine wood borers.

Sheet Piles

Sheet Piling or "bulkheading" is used to stabilize the waterfront or shoreline by preventing erosion and undercutting of soil by tide and wave action. Pilings are installed by driving or jetting into the soil and are typically backfilled either by native soils or select backfill. (See Figure 3.)

Typical sheet pilings include steel (light-to-heavy duty installations), pressure-treated wood (light-to-medium duty) as well as PVC and aluminum (light-duty). Reinforced-concrete sheet piling is also used for medium-to-heavy duty applications.

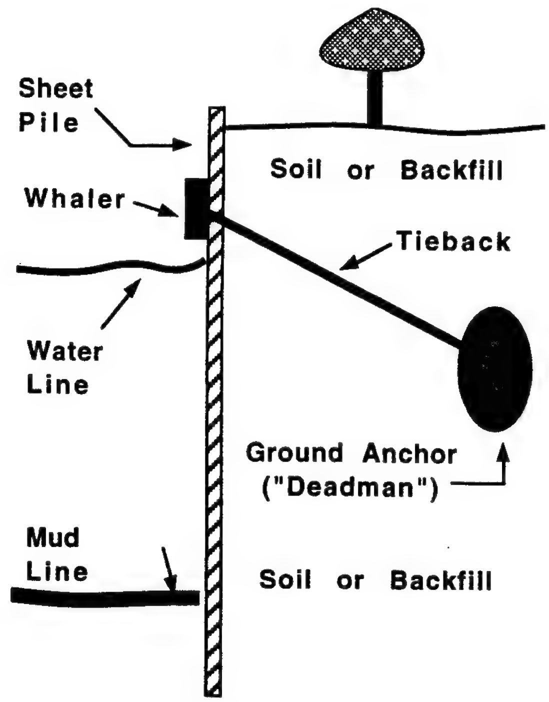

Fig. 3 Sheet Piling (Bulkheading)

ATTACHMENT C-1

PERFORMANCE TARGET GOALS FOR FENDER PILES (Ver. 6/30/95)

I. Dimensions/Appearance

1. Axial profile not to exceed a cross-section of 0.33m x 0.33m (nominal 13 in. x 13 in.) square. Cross-section can be square or round, but other shapes will be considered.

2. Shall be a single continuous pile without joints of at least 21.34m (70 ft.) in length. Longer piles may be continuous or constructed using spliced sections as long as the spliced pile meets required performance and mechanical properties as defined below.

II. Performance Requirements

1. Under normal service conditions (e.g. exposure to UV, seawater, petroleum and hydrothermal cycles), the mechanical properties as defined below shall not degrade more than 10% over the design life of the pile.

2. The pile shall have less than 5% weight increase due to water absorption (ASTM D 570, Water Absorption of Plastics).

3. Under normal service conditions the pile shall not pose a hazard to the environment. The pile shall meet pertinent standard regulatory codes/requirements for leaching, flame spread, and ignition potential.

4. The pile shall exhibit ductile behavior (minimum 20% strain at fracture) in stress-strain testing conducted perpendicular to pile axis at -40 °C (extreme winter air temperature) with a strain rate of at least 100%/minute (ASTM C 581).

5. Angle of approach from water craft is expected to cover a maximum swept angle of 180° and can be labeled on the pile for proper orientation.

III. Mechanical Properties

1. Minimum EI = 1735 kN-m^2 (6.0x10^8 lb-in^2) as determined experimentally.

2. To avoid brittle behavior, minimum outer fiber strain at fracture of 2% (as determined experimentally in bending).

3. Minimum energy absorption of 6780 joules (5.0 ft-kips).

IV. Installation/Fabrication

1. The product shall be driveable using standard equipment such as impact hammer, vibratory pile driver, and hydraulic techniques.

2. System connections will be by traditional methods such as bolting, collar, or wire wrap with staples. The product shall be drillable or hot-lanced to produce 1 inch diameter holes for bolting near the top of the pile. The pile may be labeled to indicate proper positioning for connections.

V. Cost

1. Shall demonstrate cost savings over life cycle with treated/untreated southern yellow pine. Cost comparisons to include cost of pile, installation, maintenance/repair, extraction, and disposal.

ATTACHMENT C-2

PERFORMANCE TARGET GOALS FOR BEARING PILES (Ver. 6/30/95)

I. Dimensions/Appearance

1. Cross-section may be of any shape but should not exceed 0.40m x 0.40m (nominal 16 in. x 16 in.) square.

2. Shall be a single continuous pile without joints of at least 15.25 meters (50 ft.) in length. Longer piles may be continuous or constructed using spliced sections as long as the spliced pile meets required performance and mechanical properties as defined below.

II. Performance Requirements

1. Under normal service conditions (e.g. exposure to UV, seawater, petroleum and hydrothermal cycles), the mechanical properties as defined below shall not degrade more than 10% over the design life of the pile.

2. The pile shall have less than 5% increase in weight due to water absorption (ASTM D 570, Water Adsorption of Plastics).

3. Shall have a fire resistance rating of not less than 4 hours as defined in National Fire Protection Association Bulletin #307, Construction and Fire Protection of Marine Terminals, Piers, and Wharves.

4. Under normal service conditions the pile shall not pose a hazard to the environment. The pile shall meet pertinent standard regulatory codes/requirements for leaching, flame spread, and ignition potential.

III. Mechanical Properties (Based On Southern Yellow Pine Piles)

1. Axial compressive strength of not less than 24 MPa (3500 psi) as determined experimentally.

2. Minimum EA = 40.0×10^5 kN (9.0×10^7 lb) [based upon a 267 kN (30 ton), 0.40m (16 in.) diameter pile with a compressive modulus of 3.1 GPa (450,000 psi)] as determined experimentally.

3. If using hollow FRP composite shapes (e.g., round or square tubes), the hollow areas can be filled with another material (e.g., concrete or sand) to meet the axial compressive strength and minimum EA requirements. If used, the added material must be calculated into the total system costs.

IV. Installation/Fabrication

1. The product shall be driveable using standard equipment such as drop, diesel, or pneumatic hammers, hydraulic techniques, and driving accessories.

2. Easy-to-splice sections to achieve needed lengths.

3. The product shall be drillable or hot lanced for bolt attachments to other components.

V. Cost

1. Shall demonstrate cost savings over life cycle with treated/untreated southern yellow pine. Cost comparisons to include cost of pile, installation, maintenance/repair, extraction, and disposal.

ATTACHMENT C-3

PERFORMANCE TARGET GOALS FOR SHEET PILES (Ver. 6/30/95)

I. Dimensions/Appearance

1. There is no limitation to the section width as long as the mechanical and installation requirements specified below are met.

2. The section interlocks shall be continuous along the full-length of the pile such that the constructed system meets the required performance and mechanical properties.

3. The section shall be a single continuous pile without joints of at least 21.34 m (70 ft) in length.

II. Performance Requirements

1. The pile shall have less than 5% weight increase due to water absorption (ASTM D 570, Water Absorption of Plastics).

2. Under normal service conditions (e.g., exposure to UV, petroleum products, and hydrothermal cycling), the mechanical properties as defined below shall not degrade more than 10% over the design life of the pile.

3. Under normal service conditions the pile shall not pose a hazard to the environment. The pile shall meet pertinent standard regulatory codes/requirements for leaching, flame spread, and ignition potential.

III. Mechanical Properties

1. Target goals were established to cover light-duty (e.g., beachfront), medium-duty (e.g., marina) and heavy-duty (e.g., wharf) applications. The mechanical performance target goals for each of these systems are as follows:

Light-Duty: Minimum EI = 2.33×10^3 kN-m^2/m (2.48×10^5 kip-in^2/ft) (using 3 inch Tongue &Groove timber as the target)

Medium-Duty: Minimum EI = 9.5×10^3 kN-m^2/m (1.0×10^6 kip-in^2/ft) (using SZ-12 as the target)

Heavy-Duty: Minimum EI = 5.2×10^4 kN-m^2/m (5.5×10^6 kip-in^2/ft) (using PZ-27 as the target)

If consideration is given to unexpected loading (e.g., scour at base, variable driving depths, surcharge loads), this EI requirement may be met over a critical length of the pile where needed to meet the maximum moments expected.

IV. Installation/Fabrication

1. The product shall be driveable using standard equipment such as impact hammer, vibratory driver, and hydraulic methods.

2. Specialized driving shoes shall be provided if needed for driving in firm soils.

3. Necessary connectors shall be provided if the product is to be used in conjunction with traditional (e.g., steel PZ-27) sheet pile sections.

4. The product shall be drillable or hot-lanced for bolt attachments to wale and anchor systems.

V. Cost*

1. Shall demonstrate cost savings over life cycle with installed comparative sheet pile systems made using traditional materials (e.g., steel or wood). Cost comparisons should include cost of pile, any treatment used, installation, maintenance/repair, and extraction.

Light Duty:	Material = $1.41/sf Installed = $7.00/sf
Medium Duty:	Material = $7.55/sf Installed = $13.55/sf
Heavy Duty:	Material = $13.50/sf Installed = $19.65/sf

* Cost per 1995 MEANS Building Construction Cost Data. Total construction cost equals material plus labor plus overhead and profit.

Attachment D

Testing Program

The Composite Piling CPAR team has established performance target goals that will be used to screen and evaluate conceptual designs submitted for this competition. Different tests will be conducted for each piling type (fender, bearing, and sheet) based on target performance in typical installations. Each type of experiment is identified as a task. Candidate products must be shipped to the indicated laboratory by the specified dates in the competition announcement to assure a place in the testing schedule. The quantity and length of samples to be supplied to the respective laboratory are shown below.

A confidential code will be assigned to identify each participant's candidate product. This confidential code is intended to protect your product design from other competitors. Results of this evaluation will be announced when testing is complete.

FENDER PILINGS	**TASK #**
Full-scale flexural measurements to determine EI. (To be performed warm).	F-1
Cross-sectional pinch measurements. (To be performed cold first).	F-2
Full-scale strain at fracture. (To be performed cold).	F-3
BEARING (STRUCTURAL) PILINGS	
Full-scale flexural measurements to determine EI for buckling.	ST-1
Full-scale compression of short sample to determine AE and compressive strength.	ST-2
Full-scale creep measurements of short sample. (To be performed warm).	ST-3
SHEET PILINGS	
Full-scale flexural measurements to determine EI and bending strength.	SH-1
Coupon testing to determine burst and materials properties.	SH-2
Adhesion studies to determine potential for built-up structures.	SH-3

LABORATORY ASSIGNMENTS AND SAMPLES REQUIRED

TASK #	LABORATORY	QUANTITY (each)	LENGTH(FT)
F-1	Naval Facilities Engineering Service Center (NFESC)	5	60-70
F-2	Rutgers University Center for Plastics Recycling Research (CPRR)	3	10
F-3	U.S. Army Corps of Engineers Cold Regions Research Engineering Laboratory (CRREL)	5	10
*****			
ST-1	NFESC	5	60-70
ST-2	U.S. Army Corps of Engineers Construction Engineering Research Laboratory (USACERL)	5	10
ST-3	Rutgers University CPRR	3	10
*****			
SH-1	Rutgers University Civil and Environmental Engineering (CE+E)	5	10
SH-2	Rutgers University CPRR	1	10
SH-3	Rutgers University CPRR	2	10

LABORATORY SAMPLE SHIPPING INFORMATION

(for competition participants)

USACERL: Mr. Richard Lampo, USACERL, 2902 Farber Drive, Champaign, IL 61821 phone (217) 373-6765, FAX (217) 373-6732

USACRREL: Mr. Piyush Dutta, USACRREL, 72 Lyme Road, Hanover, NH 03755-1290 phone (603) 646-4512, fax (603) 646-4640 or phone (202) 761-1843, fax (202) 761-0907

NFESC: Mr. Robert Odello, NFESC, Code: ESC 62, 560 center Drive, Port Hueneme, CA 93043-4328, phone (805) 982-1237, fax (805) 982-1409

CPRR: Dr. Tom Nosker, Rutgers University, CPRR, Building 4109, Livingston Campus, New Brunswick, NJ 08903, phone (908) 445-3632, fax (908) 445 5636

CE+E: Dr. Ali Maher, Rutgers University College of Engineering, Dept. of Civil Engineering, Brett and Bowser Rd., Piscataway, NJ 08854, phone (908) 445-2485, fax (908) 445-0577

Appendix C: Manufacturer's Specifications

Lancaster Composite, Inc.

****

CP40AN
JANUARY 1997
****

SECTION TABLE OF CONTENTS
SITE WORK
PRECAST COMPOSITE PILE

-- End of Section Table of Contents --

****

CP40AN JANUARY 1997

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PRECAST COMPOSITE PILE

****

NOTE: This guide specification covers requirements for precast composite piles, namely, concrete piles contained and stressed within a fiberglass tube. The extent and location of the work to be accomplished should be indicated on the project drawings or included in the project specification.

****

NOTE: The following information shall be shown on the drawings:

Locations and design loads of piles.
Size, shape, and length of piles.
Details of precast composite pile.
Details of splices, if required.
Locations of test piles, if required.
Soil data, where required.

1.1 REFERENCES

The publications listed below form a part of this specification to the extent referenced. The publications are referred to in the text by the basic designation only.

AMERICAN CONCRETE INSTITUTE (ACI)

ACI 211.1 (1991) Selecting Proportions for Normal, Heavyweight, and Mass Concrete
ACI 214 (1977; R 1989) Evaluation of Strength Test Results of Concrete
ACI 315 (1994) Details and Detailing of Concrete Reinforcement
ACI 318M (1995) Building Code Requirements for Reinforced Concrete (Metric)
ACI 318 (1995) Building Code Requirements for Reinforced Concrete

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM C 31 (1991) Making and Curing Concrete Test Specimens in the Field
ASTM C 33 (1993) Concrete Aggregates
ASTM C 39 (1994) Compressive Strength of Cylindrical Concrete Specimens
ASTM C 109/C 109M (1995) Compressive Strength of Cement Mortars (Using 2-in. or 50-mm Cube Specimens)
ASTM C 136 (1995; Rev. A) Sieve Analysis of Fine and Coarse Aggregates
ASTM C 143 (1990; Rev. A) Slump of Hydraulic Cement Concrete
ASTM C 150 (1995) Portland Cement
ASTM C 172 (1990) Sampling Freshly Mixed Concrete
ASTM C 494 (1992) Chemical Admixtures for Concrete
ASTM C 595M (1995) Blended Hydraulic Cements (Metric)
ASTM C 595 (1994; Rev. A) Blended Hydraulic Cements
ASTM C 618 (1995) Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete
ASTM D 1143 (1981; R 1994) Piles Under Static Axial Compressive Load

ASTM D 2310 (1991) Standard Classification for Machine-Made "Fiberglass" (Glass-Fiber Reinforced Thermosetting-Resin) Pipe
ASTM D 2996 (1995) Standard Specification for Filament-Wound "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe

ASTM D 3567 (1991) Determining Dimensions of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting Resin) Pipe and Fittings

PRECAST/PRESTRESSED CONCRETE INSTITUTE (PCI)

PCI STD-112 (1984) Standard Prestressed Concrete Piles
PCI MNL-116 (1985) Quality Control for Plants and Production of Precast Prestressed Concrete Products
PCI JR-119 (1976) Grouting of Post-Tensioned Prestressed Concrete
PCI JR-382 (1993) Design, Manufacture and Installation of Prestressed Concrete Piling

1.2 SUBMITTALS

****
NOTE: Where a "G" in asterisk tokens follows a submittal item, it indicates Government approval for that item. Add "G" in asterisk tokens following any added or existing submittal items deemed sufficiently critical, complex, or aesthetically significantly to merit approval by the Government. Submittal items not designated with a "G" will be approved by the QC organization.
****

Submit the following in accordance with Section entitled "Submittal Procedures."

1.2.1 SD-04, Drawings

****
NOTE: When the size and complexity of project warrants certification by a registered engineer, insert requirements; otherwise delete.
****
a. Piles
b. Driving helmets, capblocks, and pile cushions

1.2.1.1 Piles

Prepare in accordance with ACI 315. Indicate outside diameter and wall thickness of composite reinforcement tube. Provide sufficient detail to substantiate appropriate strength for FRP/polymer reinforcing tube. Provide certification seal of a professional engineer registered in any jurisdiction, that details of composite/polymer reinforcement tube conform with that shown on the structural design drawings. Indicate location of special embedded or attached lifting devices, employment of pick-up points, support points other than pick-up points, and any other methods of pick-up.

1.2.1.2 Driving Helmets, Capblocks, and Pile Cushions

Show details of driving helmets, capblocks, and pile cushions. Submit 2 weeks prior to [test pile installation.

1.2.2 SD-05, Design Data

a. Concrete mix design

Submit a concrete mix design before concrete is placed, for each type of concrete used for the piles.

1.2.3 SD-08, Statements

a. Precasting manufacturer's quality control procedures
b. Pile driving plan
c. Batter pile support plan
d. Suitability of pile driving equipment

1.2.3.1 Quality Control Procedures

Submit [_____ copies of precasting manufacturer's quality control procedures established in accordance with PCI MNL-116.

1.2.3.2 Installation Procedures

Submit installation instructions for pile driving plan and batter pile support plan.

1.2.4 SD-11, Factory Test Reports

a. Aggregates

1.2.4.1 Aggregates

Prior to pile fabrication, submit certified test reports for the following tests specified in ASTM C 33:
a. Grading
b. Amount of material finer than \^75 micrometers^\ \~No. 200~\ sieve
c. Organic impurities
d. Soundness
e. Clay lumps and friable particles
f. Coal and lignite
g. Weight of slag
h. Abrasion of coarse aggregate
i. Fineness modulus
j. Reactive aggregates
k. Freezing and thawing

1.2.5 SD-12, Field Test Reports

a. Concrete
b. Test piles
c. Load tests

Submit test pile records and load test data. Submit concrete cylinder compressive strength test results.

1.2.6 SD-13, Certificates

a. Prestressing steel
b. Portland cement
c. Concrete mix design

1.2.6.1 Portland Cement

Certification identifying cement; brand name, type, mill location, quantity to be used, size of lot represented by quality control sample, lot number, and destination of shipment.

1.2.6.2 Concrete Mix Design

Certify, using a Government-approved independent commercial testing laboratory, that proportioning of mix is in accordance with ACI

211.1 or \^ACI 318M^\ \~ACI 318~\ for specified strength and is based on aggregate data which has been determined by laboratory tests during last twelve months.

1.2.7 SD-17, Sample Installations

a. Test piles

1.2.8 SD-18, Records

a. Pile records

Submit pile and test pile records. Submit load test data and results.

1.3 REQUIREMENTS

1.3.1 Piling

Choose size of pile applicable to project. Provide precast composite piles, conforming where applicable to PCI JR.-382. {From test pile data the Government will determine and list "calculated" tip elevations or driving resistance's for each pile.} This information will be given to the Contractor no later than 10 days from receipt of complete test data. Use this list as the basis for ordering the piles. Do not order piles until list is provided by the Government. Test piles shall be \ ^ [1.5 [____ meter ^ \ \ ~ [5 [____ feet ~ \ longer than bid length.

1.3.2 Pile Lengths and Quantity
****
NOTE: Select the applicable paragraph(s) from the following:
****
****
NOTE: Use this paragraph for lump-sum contracts. Lump-sum method should be used in all but very special cases. Delete this paragraph for unit-price contracts. Fill in Table I as required selecting columns applicable to project. Generally, pile capacity, location, and tip elevation are shown on plans.
****
Base bids upon the number, size, capacity, and length of piles as indicated. following Table I:

Table I

Location	Number	Size	Capacity	Length

Should total number of piles or number of each length vary from that specified as the basis for bidding, an adjustment in the contract price and time for completion will be made. Adjustments in contract price will not be made for pile splices; cutting off piles; for any portion of a pile remaining above cut-off elevation; or for broken, damaged, or rejected piles.

Measurement and Payment

For unit price bid, see paragraph entitled "Basis of Bids, Measurement, and Payment" in Section 01200, Price and Payment Procedures."

PART 2 PRODUCTS

2.1 MATERIALS

2.1.1 Cement

Cement type and quantity of cement required in mix design is often dependent upon the environment, soil conditions, need for corrosion protection, and location of piling. Precast composite piles completely protect the concrete core from the environment. Chloride protection, sulfate resistance, and other exposure type problems are accordingly not issues of concern.

2.1.2 Water

Use potable water.

2.1.3 Aggregates

ASTM C 33 , except as modified herein. Provide aggregate free from any substance which may be deleteriously reactive with alkalis in cement in an amount sufficient to cause excessive expansion of concrete. Do not mix, store in same stockpile, or use fine aggregates from different sources of supply in same concrete mix or same structure without approval.

2.1.4 Admixtures

****
NOTE: For guidance in use of either water-reducing admixtures, set retarding admixtures, or combination of admixture, see ACI 543R-74, "Recommendations for Design, Manufacture, and Installation of Concrete Piles".
****
*****************If required, ASTM C 494, Type A Type B and ASTM C 618, Type N F C. Do not use mixtures containing chlorides.

****
NOTE: Superplasticizer may cause retardation of initial setting time, particularly in cold weather. Use superplasticizer as necessary to achieve proper slump (plasticity) as per admixture manufacturer's recommended procedure.
****

2.1.4.1 Expansive Agents

Admixtures that promote expansion or internal build-up of stress within the concrete core may be either of a plastic state or early hardened state variety . The expansive agents (or combinations of agents selected) shall provide for a minimum permanent positive stress of 25 psi against the inside wall of the FRP/Polymer reinforcing tube.

NOTE: Special attention should be given to assure that expansive agents, chemical stressing admixtures and other self stressing admixtures not be allowed to negatively effect compressive strength and density of approved design mix.

2.1.5 FRP/Polymer Reinforcing Tube

Hollow reinforcing tube shall be produced of polymer or composite (FRP) materials that have been formed by means of pultrusion, extrusion molding, filament winding, a combination thereof or by other methods of production.

2.1.5.1 Materials: Composition

FRP/Polymer tubes may be made of polymers or resinous materials, with or without the benefit of a fibrous reinforcement laminate design

2.1.5.2 Tube Material and Fabrication

All fiberglass tubing and fittings shall conform to the applicable requirements of ASTM D 2310 and ASTM D 2996. Tubing shall be manufactured from continuous glass roving impregnated with vinyl ester, polyester, or epoxy resin and wound under controlled tension around a highly-polished steel mandrel. The content of the structural wall shall be 60 to 70 percent glass with a minimum of 25 percent resin (by weight). Silica sand or other fillers shall not be permitted. The manufactured tubes shall be capable of withstanding normal handling, shipment, and range installation procedures. Fiberglass tube products as manufactured by Ameron, Inc., ABCO Plastics, Inc., and Specialty Plastics, Inc. conform to the standard specifications listed above.

2.1.6 Precast Composite pile

2.1.6.1 Compatibility

Material to produce the piles will be chemically compatible and physically stable throughout the life of the pile.

2.1.6.2 Stability

Dimensional and physical stability of materials used in the manufacturer of precast composite containment piles will be evaluated for compatibility by ASTM D-696-91 (Standard Test Method for Coefficient of Linear Thermal Expansion of Plastics between -30°C and 30°C).

2.1.6.3 Corrosion Resistance

FRP/Polymer Reinforcing Tube to exhibit superior corrosion and ultraviolet resistance as demonstrated when exposed to accelerated environmental test chamber for not less than 3,600 hours. The tube will show no structural failure (i.e. <10% loss of strength) as a result of exposure to moisture and lamps required in ASTM G-23, G-26, G-53 and B-117.

2.1.6.4 Color Retention

Where color is specified it will be permanent and throughout the FRP/Polymer tube. Tubes will be coated a color similar to the substrate, with not less than a 3 mil dry film thickness that when cured meets the following requirements after 3,600 hours exposure, in compliance with ASTM G-23, G-26 and G-53: a). 90% adhesion, ASTM-4541 b). Maximum color change of 25, Delta-E

2.1.6.5 Bending Strength

Unless otherwise specified all precast composite piles will have a minimum ultimate bending moment as noted on the following page: The _______ pile will have a diameter of _______ [mm/inches and an ultimate minimum bending moment of _______ [in-kips.

****

NOTE: COMPOSITE POST 40 BENDING MOMENT

PIPE DIAMETER (inches)	SECTION MODULUS (psi)	CP40 - BENDING STRENGTH (in-kips)
6 (6.625)	8.50	340
8 (8.625)	16.81	680
10 (10.750)	29.90	1210
12 (12.750)	47.10	2002
14 (14.450)	61.2	2947
16 (16.520)	91.5	4387

* See enclosed spec for strength reduction factors and other design considerations

****

2.1.6.6 Axial Strength

Unless otherwise specified all precast composite piles are to have an ultimate minimum axial strength capacity as noted below: The _______ pile will have a diameter of _______ mm/inches and an ultimate minimum axial capacity of _______ kips.

****

NOTE: COMPOSITE POST 40 AXIAL STRENGTH

PIPE DIAMETER (inches)	LENGTH (feet)	CP40 - AXIAL STRENGTH (kips)
10 (10.750)	12′ 24′ 36′ PC	2752 688 306 510
12 (12.750)	12′ 24′ 36′ PC	5384 1346 599 713
14 (14.450)	12′ 24′ 36′ PC	9052 2263 1006 925
16 (16.520)	12′ 24′ 36′ PC	15442 3860 1717 1209

* See enclosed spec for strength reduction factors and other design considerations

****

2.1.6.7 Strength Reduction Factors

Follow ACI and AASHTO structural bridge design code to assess and apply appropriate strength reduction factors as a minimum requirement.

****

NOTE: Use the following chart as a guide for evaluation:

	AASHTO	ACI
Flexural	1.	0.9
Axial	0.8	0.75
Combined	____	____

2.1.6.8 Modulus of Elasticity

Modulus of Elasticity for precast composite piles unless otherwise specified will be minimum of 2.5×10^6 psi.

2.1.6.9 Larger Sizes

For piles larger than those noted above contact the manufacturer to project ultimate load capability. Ultimate load to be verified by full scale testing.

2.1.7 Grout

Provide cement grout for piles using materials conforming to requirements stipulated herein for concrete mixes or for post-tensioned piles, PCI JR-119. Use admixtures, if required, known to have no injurious effects on steel or concrete. Do not use calcium chloride.

2.2 CONCRETE MIX DESIGN

Concrete mix design is often dependent upon the environment, soil conditions, need for corrosion protection, and location of piling. Internally stressed concrete composite pipe piles totally protect the concrete core from the environment. Chloride protection, sulfate resistance, and other exposure type problems are accordingly not issues of concern.

2.2.1 Core Characteristics

Core mix design to be a minimum 6000 psi compressive strength. Core materials to be expansive in nature and must set to a permanent positive stress, with a minimum outward expansion of 20 psi. All material to be provided by an approved batch plant. Follow P.C.I. / PSI Q.C. standards as a minimum for all casting procedures.

2.3 FABRICATION OF PRECAST COMPOSITE PILES

2.3.1 Formwork

The FRP/polymer reinforcing tube remains as an integral part of a precast composite pile. There is no formwork required for piles except where additional support may be necessary to hold the sectional shape within specified tolerances during the curing process.

2.3.2. Stay-in-Place Forms

Stay in place forms shall be braced and stiffened against deformation, accurately constructed, watertight, and supported on unyielding casting beds. Forms shall prevent movement of pile without damage from internal stress forces. Form precast dowel holes with FRP tubing. [Inside forms or void tubes not to be grouted may be treated cardboard, plywood, or other material.

Anchor void forms firmly so they will not move, float or collapse during placing concrete. If a moving mandrel is used for forming inner void, take special precautions to prevent fallout of inner surfaces, tensile cracks, and separation of concrete and stay in place forms. Make piles to dimensional tolerances in accordance with PCI MNL-116.

2.3.3 Pretensioning FRP/polymer Reinforcing Tube

Where fibrous rovings are used to form a reinforcing laminate in the FRP/Polymer reinforcing tube the rovings are to be pretensioned and held in tension (minimum of 5 to 10 lbs.) during the cure of the resin matrix, as an integral part of the manufacturing process.

2.3.4 Casting

Unless otherwise specified, PCI MNL-116-85 shall govern all quality control procedures.

2.3.4.1 Conveying

Clean conveying equipment thoroughly before each run. Convey concrete from mixer to stay-in- place forms as rapidly as practicable by methods which will not cause segregation or loss of ingredients. Deposit concrete as nearly as practicable to its final position. During placing, make any free vertical drop of the concrete less than \ 0.91 m \ \ 3 feet \. Remove concrete which has segregated in conveying or placing. Use superplasticizer to gain proper slump for conveying, placing, and casting.

2.3.4.2 Placing or Casting

Perform concrete casting into stay-in-place forms when anchorage and provisions for voids have been inspected and approved by pile manufacturer's quality control representative. Produce each pile of dense concrete straight with reinforcement tube retained in its proper position during fabrication. FRP/Polymer reinforcing tubes must be held straight in both directions (horizontal and vertical) during the curing process. Vibrators to be located in steel framework of casting beds at intervals of not less than 15 feet. Quality control plan to demonstrate proper technique where concrete is neither over or under vibrated. All piles to be fitted with a polymer cap top and bottom.

2.3.5 Curing

Moist curing occurs naturally as the concrete is enclosed within the reinforcing tube during the cure process. Do not exceed 40 : 1 cement to water ratios in concrete design mixes. Slump to be within 3 to 4 inches (water slump), with a plasticity range of 8 to 12 inches as specified. Plasticity to be regulated by the use of a second generation plasticizer.

2.3.6 Design Formula

Classical analytical formulas to be submitted and be verified by full scale tests when required by owner. Tests that fail will be paid for by the contractor, successes by the owner.

2.4 EQUIPMENT

2.4.1 Pile Hammers

Furnish a hammer capable of developing the indicated ultimate pile capacity considering hammer impact velocity; ram weight; stiffness of hammer and pile cushions; cross section, length, and total weight of pile; and character of subsurface material to be encountered. Use the same type pile hammer, operating at the same rate and in the same manner, as that used for driving test piles. Obtain required driving energy of hammer, except for diesel hammers, by use of a heavy ram and a short stroke with low impact velocity. At final

driving, operate pile hammer in accordance with manufacturer's recommendation for driving either end bearing piles or friction piles. At final driving, operate diesel powered hammers at rate recommended by manufacturer for hard driving. Maintain pressure at steam or air hammer so that: (1) for double-acting hammer, the number of blows per minute during and at completion of driving of a pile is equal approximately to that at which hammer is rated; (2) for single-acting hammer, there is a full upward stroke of the ram; and (3) for differential type hammer, there is a slight rise of hammer base during each downward stroke.

2.4.2 Driving Helmets and Cushion Blocks

2.4.2.1 Driving Helmets or Caps and Pile Cushions

****

NOTE: Insert minimum and maximum thicknesses for pile cushion. An absolute minimum would be \^75 mm^\ \~3 inches~\ and the actual required thickness would depend upon pile length, hammer energy, design load, required final penetration resistance, and character of subsurface material to be encountered. Generally thicker blocks are required for longer piles, larger hammers, and harder driving. A Wave Equation analysis is useful in determining required thicknesses for pile cushion. Minimum thickness is to protect head of pile. Pile cushion should also have a maximum thickness to insure effective driving. Select when pile cushion is to be replaced. It is generally recommended that a new pile cushion be used at the start of driving of each pile.

****

Use a steel driving helmet or cap including a pile cushion between top of pile and driving helmet or cap to prevent impact damage to pile. Use a driving helmet or cap and pile cushion combination capable of protecting pile head, minimizing energy absorption and dissipation, and transmitting hammer energy uniformly over top of pile. Provide driving helmet or cap fit sufficiently loose around top of pile so that pile may be free to rotate without binding within driving helmet. [During test pile installation, demonstrate to satisfaction of Contracting Officer that equipment to be used on project performs specified function. Use pile cushion of solid wood or of laminated construction using plywood, softwood or hardwood boards with grain parallel to end of pile. Provide pile cushion with thickness of [_____ \^mm^\ \~inches~\ minimum and [_____ \^mm^\ \~inches~\ maximum. Replace pile cushion [at start of driving of each pile [when it becomes highly compressed, charred or burned, or has become spongy or deteriorated in any manner.

2.4.2.2 Hammer Cushion or Capblock

****

NOTE: Select either wood or aluminum/micarta capblock. Delete inappropriate sentences. An aluminum/micarta capblock is recommended because of its consistent elastic properties and long life.

If final pile penetration resistance is based on a Wave Equation analysis, the type capblock used should be the same as that used in the analysis.

****

Use a hammer cushion or capblock between driving helmet or cap and hammer ram consisting of a solid hardwood block with grain parallel to the pile axis and enclosed in a close-fitting steel housing aluminum and micarta (or equal) discs stacked alternately in a steel housing. Use steel plates at top and bottom of capblock. Replace wood capblock when it becomes highly compressed, charred or burned or becomes spongy or deteriorated in any manner. Replace aluminum or micarta discs that have become damaged, split or deteriorated in

any manner. Do not replace wood capblock during final driving of any pile. Do not use small wood blocks, wood chips, rope or other materials that permit excessive loss of hammer energy.

2.5 PRODUCT QUALITY CONTROL

Where piling is manufactured in a plant with an established quality control program as attested to by a current certification in the PCI "Certification Program for Quality Control" perform product quality control in accordance with PCI MNL-116. Where piling is manufactured by specialists or in plants not currently enrolled in the PCI "Certification Program for Quality Control," set-up a product quality control system in accordance with PCI MNL-116 and perform concrete and aggregate quality control testing using an independent commercial testing laboratory approved by the Contracting Officer in accordance with the following.

2.5.1 Aggregate Tests

Take samples of fine and coarse aggregate at concrete batch plant and test. Perform mechanical analysis (one test for each aggregate size) in accordance with ASTM C 136. Tabulate results of tests in accordance with ASTM C 33.

2.5.2 Strength Tests

Sample concrete in accordance with ASTM C 172 at time concrete is deposited for each production line. Perform slump tests in accordance with ASTM C 143. Mold cylinders in accordance with ASTM C 31. Mold at least six cylinders per day or one for every \^[15 [45 cubic meter^\ \~[20 [60 cubic yards~\ of concrete placed, whichever is greater. Cure cylinders in same manner as piles and for accelerated curing, place at coolest point in casting bed. Perform strength tests in accordance with ASTM C 39. Test two cylinders of each set at 7 days or 14 days, or at a time for establishing transfer of prestressing force (release strength) and removal of pile from forms. Test remaining cylinders of each set 28 days after molding.

2.5.3 Changes in Proportions

If, after evaluation of strength test results, compressive strength is less than specified compressive strength, make adjustments in proportions and water content and changes in temperature, moisture, and curing procedures as necessary to secure specified strength. Submit changes in mix design to Contracting Officer in writing.

2.5.4 Compressive Strength Test Results

Evaluate compressive strength test results at 28 days in accordance with ACI 214 using a coefficient of variation of 10 percent. Evaluate strength of concrete by averaging test results of each set of standard cylinders tested at 28 days. Not more than 10 percent of individual cylinders tested shall have a compressive strength less than specified average compressive strength.

PART 3 EXECUTION

3.1 PILE DRIVING

3.1.1 Driving Piles

****

NOTE: Delete items in brackets dealing with tip elevation and driving resistance when test piles or

load tests are not used. Delete item in brackets regarding predrilling or jetting when procedure is
not used. If needed, insert maximum hammer energy for no tip resistance. This can be determined by comparing tensile stresses in pile resulting from a Wave Equation Analysis with effective prestress in pile.
****

Drive piles to or below "calculated" indicated tip elevation [to reach a driving resistance in accordance with the schedule which the Government will prepare from the test-pile driving data. During initial driving and until pile tip has penetrated beyond layers of very soft soil [or below bottom of predrilled or prejetted holes, use a reduced driving energy of the hammer of [_____ \^joules^\ \~foot pounds~\ per blow maximum or as otherwise directed by Contracting Officer. Remove fluid soil and water rising inside hollow pile more than \^3 m^\ \~10 feet~\ above the original ground or water level or to within \^1.5 m^\ \~5 feet~\ of pile top before driving is continued, unless methods approved by Contracting Officer are used to prevent pile damage. If a pile fails to reach "calculated" indicated tip elevation, or if a pile reaches "calculated" tip elevation without reaching required driving resistance, Notify Contracting Officer and perform corrective measures as directed. Provide hearing protection when noise levels exceed 140 dB.

3.1.2 Protection of Piles
****
NOTE: Delete references to batter piles when not applicable to the project.
****
Take care to avoid damage to piles during handling, placing pile in leads, and during pile driving operations. Support piles laterally during driving, but allow rotation in leads. Take special care in supporting battered piles to prevent excessive bending stresses in pile. Square top of pile to longitudinal axis of pile. Maintain axial alignment of pile hammer with that of the pile. Use a special driving head to drive piles having strands or mild steel reinforcement projecting from head.

3.1.3 Tolerances in Driving
****
NOTE: Omit references to batter piles when not applicable to the project. Select appropriate tolerances for type of pile.
****
Drive piles with a variation of not more than 2 percent from vertical for plumb piles or more than 4 percent from required angle for batter piles. Maintain and check axial alignment of pile and leaders at all times. If subsurface conditions cause pile drifting beyond allowable axial alignment tolerance, notify Contracting Officer and perform corrective measures as directed. Place butts within \^100 mm^\ \~4 inches~\ of location indicated. Manipulation of piles within specified tolerances is permitted, to a maximum of 1 1/2-percent of their exposed length above ground surface or mudline. In addition to specified tolerances, maintain a location to provide a clear distance of at least \^125 mm^\ \~5 inches~\ from butt to edge of pile cap. If clear distance can not be maintained, then notify Contracting Officer. Check each pile for heave. Redrive heaved piles to required point elevation.

3.1.4 [[Jetting [Pre-Drilling of Piles
****
NOTE: Jetting should generally not be permitted. See note for paragraph entitled "Test Piles."

****
Discontinue at a depth approximately \^1.5 m^\ \~5 feet~\ above "calculated" tip elevation, and achieve remaining penetration by driving. Before starting final driving set pile to within \^300 mm^\ \~one foot~\ of jetted, pre-drilled, or spudded depth and firmly seat piles in place by application of a number of reduced energy hammer blows.

3.1.5 Splices
****
NOTE: Splicing of piles normally should not be permitted except where extremely long or heavy piles are required. If splices are permitted, drawings should indicate splice details. (See PCI standard drawings for typical splice details).
****
Splicing of piles is not permitted. Make splices as indicated. Payment will be made as an adjustment to the contract price.

3.1.6 Build-Ups

3.1.6.1 Pretensioned Piles
****
NOTE: Insert compressive strength required by design, usually a minimum of \^35 MPa^\ \~5,000
psi~\. Insert maximum percent of build-ups permitted for project. The percent will depend on
criticality of pile failure at build-up; whether the top of the pile is designed as a moment connection;
exposure of piles to external physical or corrosive damage. Normally, for piles supporting piers
exposed to seawater, limit percentage of build-ups to 10 percent.
****

Where required, pile section may be extended to cut-off elevation by means of a cast-in-place reinforced concrete build-up. Make build-up in accordance with PCI STD-112. Construct build-ups made after completion of driving in accordance with detail, "Build-Up Without Driving." Make build-ups to be driven in accordance with detail "Build-Up With Driving." Have details of means for protecting joints by a suitable mortar or epoxy approved by Contracting Officer. Where build-ups are exposed to water, protect cast-in-place section from water during curing period. Concrete in build-up shall have a minimum compressive strength of [_____ \^MPa^\ \~psi~\. Build-ups will not be permitted on more than [_____ percent of total number of piles. If this percent figure is exceeded, or if in the judgment of the Contracting Officer, the clustered location of build-ups is undesirable, withdraw piles of insufficient length and replace with longer piles. Payment for such withdrawal and replacement will be made as an adjustment to the contract price.

3.1.6.2 Post-Tensioned Piles

Build-up piles to specified cut-off elevation by a cast-in-place extension of the pile, by a pile section, or by use of an acceptable length of pile cut-off. Make splice between pile and build-up by a poured plug of reinforced concrete extending a minimum of one outside-pile-diameter into the pile and an equal length into build-up where possible. Splice plug may be an extension of pile-to-cap connecting plug. If pile tops are damaged during driving, remove damaged portion and build-up pile as necessary.

3.1.7 Pile Cut-Off

Cut off piles with a smooth level cut using pneumatic tools, sawing, or other suitable methods approved by Contracting Officer. Use of explosives for cutting is not permitted.

3.1.8 Protection from Freezing

For hollow piles exposed to freezing, provide precast drain holes through pile wall at approximate ground water elevation and fill pile with free-draining material. For piles standing in open water, place a concrete plug from lowest freeze depth to a minimum of \^300 mm^\ \~one foot~\ above maximum high water level and provide precast drain holes through pile wall just above surface of concrete plug.

3.2 FIELD QUALITY CONTROL

3.2.1 Test Piles

****

NOTE: Indicate location and number (if required) of piles (first option) on plans. Where second option is used, list appropriate soil boring test hole numbers. Jetting should generally not be permitted for piles:

1. Dependent on side friction in fine-grained low permeability soils (high clay or silt content) where considerable time is required for the soil to reconsolidate around the piles.
2. Subject to uplift or lateral forces.
3. Adjacent to existing structures.
4. In closely spaced clusters unless the load capacity is confirmed by test.

****

Use test piles of type, and drive as specified for piling elsewhere in this section. The Government will use Contractor test pile data to determine "calculated" pile tip elevation or necessary driving resistance. Drive test piles at the locations indicated in vicinity of soil boring test holes Nos. _____, _____, and _____. Drive test piles to [indicated tip elevation indicated bidding lengths. Drive piles driven one day an additional \^150 mm^\ \~6 inches~\ on the next working day, unless refusal (20 blows per \^25 mm^\ \~one inch~\ is encountered). Record any increase or decrease in driving resistance. If there is a decrease in driving resistance, a load test, at Government expense, may be required by the Contracting Officer. Use test piles, if located properly and offering adequate driving resistance in finished work. Pre-drilling or jetting is permitted only when test piles clearly establish validity of its use, or as directed by the Contracting Officer.

3.2.2 Load Tests

****

NOTE: If pile load tests are required and approved by the Contracting Officer, specify number and location of piles. Select method of load test. In ASTM D 1143, permit anchor piles only if approved by EFD Code 411, Geotechnical Branch. Insert figure (tons) corresponding to 225 percent of the design load. Select appropriate acceptance criteria. The offset method (first option) is usually recommended.

****

Perform load tests on _____ piles in accordance with ASTM D 1143 as modified herein. Do not use anchor piles. Provide apparatus for applying vertical loads as required by method, using load from weighted box or platform or reaction frame attached to sufficient uplift piles to safely take required load applied to pile by hydraulic jack. Increase load in increments until rapid progressive settlement takes place or until application of total load of \^_____ metric tons^\ \~_____ tons~\. Consider load test satisfactory when

after one hour at full test load gross settlement of pile butt is not greater than gross elastic pile compression plus \^4 mm^\ \~0.15 inch~\ plus one percent of pile tip diameter or width in \^mm^\ \~inches~\, slope of gross load-settlement curve under full test load does not exceed \^1.5 mm per metric ton^\ \~0.05 inches per ton~\, net settlement after removal of test load does not exceed \^19 mm^\ \~3/4 inch~\. Make load tests at locations shown on driven test piles. Additional load tests, at Government expense, may be required by the Contracting Officer. Loading, testing, and recording and analysis of data must be under the direct supervision of a Registered Professional Engineer provided and paid for by the Contractor.

3.2.3 Pile Records

****

NOTE: Omit reference to load test when not required in project. Omit reference to test piles and "calculated tip elevation" when test piles are not driven. Where special or unusual soil conditions are expected, consultation with EFD Code 411, Geotechnical Branch regarding special engineering supervision of driving, testing, recording and analysis of data for project may be useful.

****

For each driven pile, keep a record of the number of blows required for each \^meter^\ \~foot~\ of penetration and number of blows for the last \^150 mm^\ \~6 inches~\ penetration or fraction thereof as required for the "calculated" driving resistance. Include in the record the beginning and ending times of each operation during driving of pile, type and size of hammer used, rate of operation, stroke or equivalent stroke for diesel hammer, type of driving helmet, and type and dimension of hammer cushion (capblock) and pile cushion used. Record retap data and unusual occurrences during pile driving. Notify Contracting Officer 10 days prior to driving of test piles and load test. \&The following log is a preprinted form for recording pile driving data.&\\^

PILE DRIVING LOG

CONTRACT NO.____________________ CONTRACT
NAME____________________
CONTRACTOR________________________ TYPE OF
PILE__________________
PILE LOCATION__________ PILE SIZE: BUTT/TIP: ________
LENGTH________
GROUND ELEVATION____________________ CUT OFF
ELEVATION____________
PILE TIP ELEVATION______________ VERTICAL (_____)
BATTER 1 ON (_____)
SPLICES ELEVATION________________
COMPANY________________________
HAMMER: MAKE & MODEL_____________ WT.
RAM___________________
STROKE___________________ RAM RATED
ENERGY______________________
DESCRIPTION & DIMENSIONS OF DRIVING
CAP____________________________
CUSHION MATERIALS &
THICKNESS____________________________________
INSPECTOR____

"DEPTH" COLUMN OF PILE DRIVING RECORD REFERENCED TO:
__________________ CUT-OFF ELEVATION
__________________ FINISH FLOOR ELEVATION

TIME: START DRIVING _______ FINISH DRIVING ________ DRIVING TIME__________
INTERRUPTIONS (TIME, TIP ELEV. & REASON)
____
JET PRESSURE & ELEVATIONS________________
____

DRIVING RESISTANCE

DEPTH M	NO. OF BLOWS	DEPTH M	NO. OF BLOWS	DEPTH M	NO. OF BLOWS
0	______	5.4	______	10.8	______
0.3	______	5.7	______	11.1	______
0.6	______	6.0	______	11.4	______
0.9	______	6.3	______	11.7	______
1.2	______	6.6	______	12.0	______
1.5	______	6.9	______	12.3	______
1.8	______	7.2	______	12.6	______
2.1	______	7.5	______	12.9	______
2.4	______	7.8	______	13.2	______
2.7	______	8.1	______	13.5	______
3.0	______	8.4	______	13.8	______
3.3	______	8.7	______	14.1	______
3.6	______	9.0	______	14.4	______
3.9	______	9.3	______	14.7	______
4.2	______	9.6	______	15.0	______
4.5	______	9.9	______	15.3	______
4.8	______	10.2	______	15.6	______
5.1	______	10.5	______	15.9	______

SHEET 1 OF 2

16.2	______	23.1	______	29.7	______
16.5	______	23.4	______	30.0	______
16.8	______	23.7	______	30.3	______
17.1	______	24.0	______	30.6	______
17.4	______	24.3	______	30.9	______
17.7	______	24.6	______	31.2	______
18.0	______	24.9	______	31.5	______
18.3	______	25.2	______	31.8	______
18.6	______	25.5	______	32.1	______
18.9	______	25.8	______	32.4	______
19.2	______	26.1	______	32.7	______
19.5	______	26.4	______	33.0	______
19.8	______	26.7	______	33.3	______
20.1	______	27.0	______	33.6	______
20.4	______	27.3	______	33.9	______
20.7	______	27.6	______	34.2	______
21.0	______	27.9	______	34.5	______
21.3	______	28.2	______	34.8	______
21.6	______	28.5	______	35.1	______
21.9	______	28.8	______	35.4	______
22.2	______	29.1	______	35.7	______
22.5	______	29.4	______	36.0	______
22.8	______				

Driving resistance in blows per 25 mm for last 0.30 m of penetration:
DEPTH________
DEPTH________
25mm___ 50mm___100mm___125mm___150mm___175mm___200mm___225mm___
250mm___

275mm____300mm____
ELEV.__________
ELEV.___________
REMARKS____
____
____
____

CUT OFF ELEVATION: FROM DRAWING
____
TIP ELEVATION = GROUND ELEVATION - DRIVEN DEPTH =
____
DRIVEN LENGTH = CUT OFF ELEVATION - TIP ELEVATION =
____
CUT OFF LENGTH = PILE LENGTH - DRIVEN LENGTH =
____

SHEET 2 OF 2

PILE DRIVING LOG
CONTRACT NO.______________________________ CONTRACT
NAME_____________________________
CONTRACTOR____________________________________ TYPE OF
PILE__________________________
PILE LOCATION________________ PILE SIZE: BUTT/TIP: __________
LENGTH ___________
GROUND ELEVATION______________________________ CUT OFF
ELEVATION_________________
PILE TIP ELEVATION_____________________ VERTICAL (______)
BATTER 1 ON (______)
SPLICES ELEVATION_________________________
COMPANY___________________________________
HAMMER: MAKE & MODEL____________________ WT.
RAM____________________________
STROKE___________________________ RAM RATED
ENERGY_____________________________________
DESCRIPTION & DIMENSIONS OF DRIVING
CAP____
CUSHION MATERIALS &
THICKNESS____
INSPECTOR____
____

"DEPTH" COLUMN OF PILE DRIVING RECORD REFERENCED TO:
__________________________ CUT-OFF ELEVATION
__________________________ FINISH FLOOR ELEVATION
TIME: START DRIVING_________ FINISH DRIVING__________ DRIVING
TIME__________
INTERRUPTIONS (TIME, TIP ELEV. &
REASON)____
JET PRESSURE &
ELEVATIONS____
____
____

DRIVING RESISTANCE

DEPTH FT.	NO. OF BLOWS	DEPTH FT.	NO. OF BLOWS	DEPTH FT.	NO. OF BLOWS
0	______	18	______	36	______
1	______	19	______	37	______
2	______	20	______	38	______
3	______	21	______	39	______
4	______	22	______	40	______
5	______	23	______	41	______
6	______	24	______	42	______

7	______	25	______	43	______
8	______	26	______	44	______
9	______	27	______	45	______
10	______	28	______	46	______
11	______	29	______	47	______
12	______	30	______	48	______
13	______	31	______	49	______
14	______	32	______	50	______
15	______	33	______	51	______
16	______	34	______	52	______
17	______	35	______	53	______

SHEET 1 OF 2

54	______	77	______	99	______
55	______	78	______	100	______
56	______	79	______	101	______
57	______	80	______	102	______
58	______	81	______	103	______
59	______	82	______	104	______
60	______	83	______	105	______
61	______	84	______	106	______
62	______	85	______	107	______
63	______	86	______	108	______
64	______	87	______	109	______
65	______	88	______	110	______
66	______	89	______	111	______
67	______	90	______	112	______
68	______	91	______	113	______
69	______	92	______	114	______
70	______	93	______	115	______
71	______	94	______	116	______
72	______	95	______	117	______
73	______	96	______	118	______
74	______	97	______	119	______
75	______	98	______	120	______
76	______				

DRIVING RESISTANCE IN BLOWS PER INCH FOR LAST FOOT OF PENETRATION:
DEPTH__________
DEPTH__________
1"____2"____3"____4"____5"____6"____7"____8"____9"____10"____11"____12"____
ELEV.__________
ELEV.__________
REMARKS____

CUT OFF ELEVATION: FROM DRAWING

TIP ELEVATION = GROUND ELEVATION - DRIVEN DEPTH =

DRIVEN LENGTH = CUT OFF ELEVATION - TIP ELEVATION =

CUT OFF LENGTH = PILE LENGTH - DRIVEN LENGTH =

SHEET 2 OF 2

Creative Pultrusions, Inc.

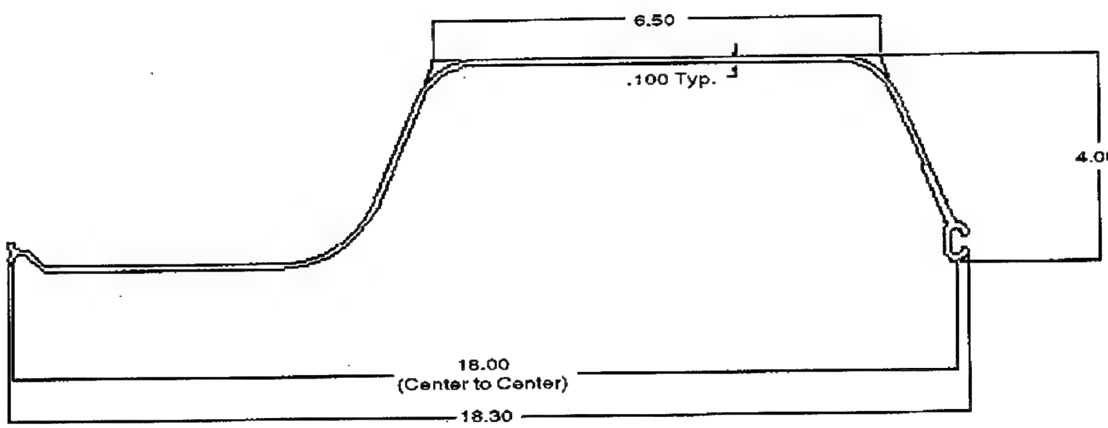
DATA SHEET

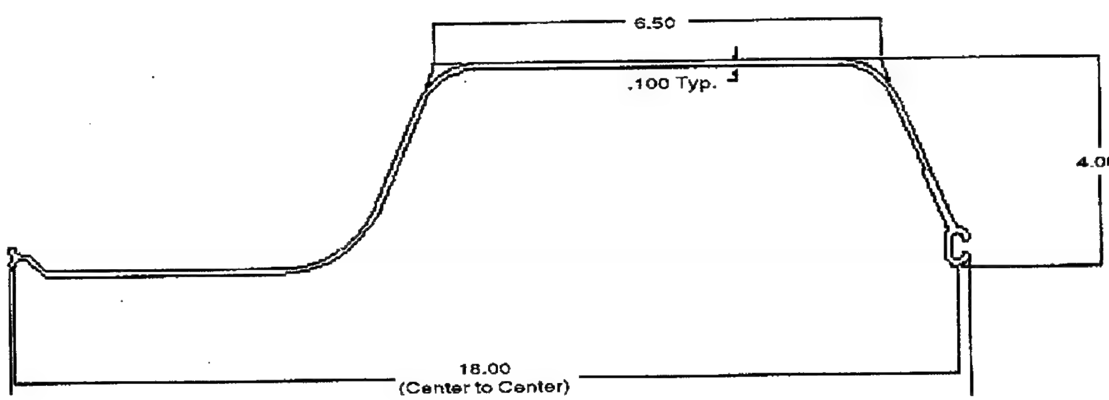
Seawall High-Strength Composite Bulkheads

Property Values

Physical Properties	Unit	Value
Material	--	Fiberglass reinforced composite
Weight	Lb./Linear Ft.	1.8735
Thickness	In.	0.100
Linear coverage/sheet	In.	18.0
Depth of cross section	In.	4.0

Mechanical Properties	Unit	Longitudinal	Transverse
Tensile strength	Lb./In.2	30.00	7.00
Flexural strength	Lb./In.2	30.00	10.00
Flexural modulus	Lb./In.2	1.6 x 106	0.8 x 106
Moment of Inertia: in4 = 80.87 in4	Ix = 6.79 Iy	6.79	80.87





Seaward International, Inc.

(Please note that a similar specification for a 16-in. diameter pile for fender or loadbearing applications is also available from Seaward International.)

FIBERGLASS REINFORCED PLASTIC COMPOSITE MARINE FENDER PILE,

13″ DIAMETER WITH EIGHT (8) EACH 1.25″ DIAMETER FIBERGLASS REINFORCING ELEMENTS

1. SCOPE

1.1 Scope. This specification covers a fiberglass reinforced plastic composite marine fender pile to be used for protection of ships, barges, harbor craft, wharves, bridges and piers from damage between the interface of vessel to pier.

2. APPLICABLE DOCUMENTS

2.1 Publications. The following documents form a part of this specification to the extent specified herein.

ASTM D543	-	Resistance of Plastics to Chemical Reagents
ASTM D570	-	Water Absorption of Plastics
ASTM D638	-	Tensile Properties of Plastics
ASTM D695	-	Compressive Properties of Rigid Plastics
ASTM D746	-	Brittleness Temperature of Plastic and Elastomers by Impact
ASTM D792	-	Specific Gravity (Relative Density) and Density of Plastics by Displacement

ASTM D1761	-	Method of Testing Mechanical Fasteners in Wood (Section 102)
ASTM D2240		Rubber Property-Durometer Hardness
ASTM D4060	-	Abrasion Resistance of Organic Coatings by the Taber Abraser
ASTM D4329	-	Operating Light and Water Exposure Apparatus (Fluorescent UV Condensation Type) for Exposure of Plastics (UVA-340)
ASTM D4476	-	Flexural Properties of Fiber Reinforced Pultruded Plastic Rods
ASTM E12	-	Density and Specific Gravity of Solids, Liquids and Gases
ASTM F489	-	Static Coefficient of Friction

2.2 Order of precedence. In the event of a conflict between the text of this specification and the references cited herein (except for associated detail specifications or specification sheets), the text of this specification shall take precedence. Nothing in this specification, however, shall supersede applicable laws and regulations unless a specific exemption has been obtained.

2.3 Submittals. The manufacturer shall submit to the purchasing authority one (1) copy each of his standard and most recent product brochure and Technical Manual for the product covered by this specification. Copies of material test reports and performance test data which support compliance with the specification requirements shall be submitted to the purchasing authority as required by the procurement documents.

3. REQUIREMENTS

3.1 Standard commercial product. The fiberglass reinforced plastic composite marine fender pile shall be in accordance with the requirements of this specification and shall be the manufacturer's standard commercial product. Additional or better features which are not specifically prohibited by this specification, but which are a part of manufacturer's standard commercial product, shall be included in the piling being furnished. A standard commercial product is a product which has been sold or is being currently offered for sale on the commercial market through advertisements or manufacturer's catalogs or brochures, and represents the latest production model. Manufacturer shall provide documentation that it has manufactured the product for a minimum of 4 years.

3.2 Drawings. The contractor is responsible for preparing his own shop drawings. Where tolerances prescribed may cumulatively result in incorrect fits, the contractor shall provide tolerances within those prescribed herein to insure correct fit, assembly, and operations of the items. No deviation from the prescribed dimensions or tolerances is permissible without prior approval of the purchaser.

3.3 Materials. Materials used shall be free from defects which would adversely affect the performance or maintainability of individual components or of the overall assembly. Materials not specified herein shall be of the same quality used for the intended purpose in commercial practice.

3.3.1 Plastic. The plastic shall be a mixture of one or more of the following recycled post consumer or post industrial thermoplastics: High density polyethylene, medium density polyethylene, low density polyethylene, and polypropylene This plastic shall be mixed with the appropriate colorants, UV inhibitors and antioxidants, so that the resulting plastic portion of the product shall conform to the characteristics as listed in Table I.

3.3.2 Reinforcing. The plastic composite marine fender pile shall be reinforced with fiberglass elements. The reinforcing elements shall conform to the characteristics found in Table II.

3.4 Design. The fiberglass reinforced plastic composite marine fender pile shall be designed as described herein.

General Configuration. The plastic composite marine fender pile shall have a round shape with both ends cut flat. It shall be seamless with a smooth outer skin.

TABLE I. PLASTIC (TYPICAL PROPERTIES)

Density (ASTM D792)	Skin	55-63 lb./cu. ft
Density (ASTM E12)	Core/Annulus	34-50 lb./cu. ft
Water Absorption (ASTM D570)	Skin Core/Annulus	24 hr.: < 0.5% wt. Increase 2 hr.: < 1.0% wt. Increase 24 hr.: < 3.0% wt. increase
Brittleness (ASTM D746)	Skin	No break at -40°F
Impact Resistance (ASTM D746 modified)	Skin	Greater than 4 ft-lb./in.
Hardness (ASTM D2240)	Skin	45-55 (Shore D)
Ultraviolet (ASTM D4329 UVA-340)	Skin/Core/Annulus	No more than 10% change in Shore D durometer hardness after 500 hours exposure
Abrasion (ASTM D4060)	Skin	Weight Loss:< 0.5 g Wear Index: 2.5 to 3.0 Cycles = 10,000 Wheel = CS17 Load = 1 kg
Chemical Resistance (ASTM D543)	Skin/Core/Annulus Sea Water Gasoline No. 2 Diesel	< 1.5% weight increase < 7.5% weight increase < 6.0% weight increase
Tensile Properties (ASTM D638)	Skin/Core/Annulus	Minimum 500 psi at break
Compressive Modulus (ASTM D695)	Skin/Core/Annulus	Minimum 40,000 psi
Coefficient of Friction (ASTM F489)	Skin	Maximum 0.25, wet or dry
Nail Pull Out (ASTM D1761 Section 102)	Skin/Core/Annulus	Minimum 60 lb.

TABLE II. REINFORCING

For Fiberglass Reinforcing Elements:

Tensile Properties (ASTM D638)	Ultimate Tensile Strength	70,000 psi
Flexural Strength (ASTM D790)	Flexural Strength	70,000 psi
Compressive Properties (ASTM D695)	Compressive Strength	40,000 psi

3.4.2 Dimensions. Dimensions for the fiberglass reinforced plastic composite marine fender pile shall be as shown in Table III.

TABLE III. DIMENSIONS

Fender Pile	Dimension	Tolerance
Length	Per order (105 feet maximum)	+/-1.0 feet
Overall Diameter	13 inches	+/-0.250 inches
Outer Skin Thickness	3/16 inches	+/-0.125 inches
Reinforcing Element Circle Diameter (as defined by the outer edges of the reinforcing elements)	11.5 inches	+/-1.0 inches
Straightness (gap, bend or bulge inside while lying on a flat surface)		< 1.5 inches per 10 feet of length

3.4.3 Reparability. The outer skin must be repairable if chipped or spalled by using a commercially available plastic roofing compound.

3.5 Construction. The plastic composite marine fender piling shall be manufactured in a continuous process that will result in the piling having no joints. The plastic composite marine fender piling shall have a coextruded outer skin of dense plastic, an inner core of foamed plastic manufactured prior to the manufacture of the piling, and an annulus of foamed plastic encapsulating the reinforcing elements. The plastic composite marine fender pile shall conform to the design requirements of Section 3.4 of the specification.

3.5.1 Outer Skin. The outer skin of the plastic composite marine fender pile shall be produced so that it is continuous and homogenous throughout the entire length and circumference of the piling. It shall be formed by coextruding a plastic material at the same time that the annulus material is extruded. It shall conform to those applicable Sections of Table I, and should be black in color unless otherwise specified in the purchase documents.

3.5.2 Inner Core. The inner core of the plastic composite marine fender piling shall be a continuous foamed structure throughout the entire length of the piling. It shall conform to those applicable Sections of Table I, and shall be black in color. Butt joints as required for manufacturing may be utilized provided the full strength of the plastic is developed in the joint.

3.5.3 Annulus. The annulus of the piling shall be a continuous foamed structure throughout the entire length of the piling. It shall conform to those applicable Sections of Table I, and shall be black in color. The annulus shall be bonded to the inner core by melting the inner core, in such a manner that the joint between the inner core and the annulus develops the full strength of the plastic.

3.5.4 Reinforcing. The reinforcing elements shall be arranged in a concentric pattern, as described in Table III, within the annulus of the plastic composite marine fender piling. Each plastic composite marine fender pile shall have a quantity of eight (8) fiberglass reinforcing elements, 1.25" inch in diameter. Each individual element shall typically run the entire length of the piling, to within 1.0 feet from either end. No plastic, fiberglass or metal elements or supports for the reinforcing element shall be used in the piling.

3.5.5 Owners Field Guide. With the shipment of the first plastic composite marine fender pile, the manufacturer shall provide one copy of its owners field guide. This guide shall include information and diagrams describing and illustrating the recommended means for handling, placing, driving, and finishing the plastic composite marine fender pile.

3.6 Performance. The plastic composite marine fender pile shall be designed to provide the following structural characteristics when using the material properties shown in Tables I and II.

Flexural Modulus of Elasticity	>570,000 psi
Stiffness (EI)	>8.0 x 10^8 lb·in^2
Yield Stress in Bending	>4,800 psi
Weight	41-50 lb./ft.

3.7 Interchangeability. All units of the same classification furnished with similar options under a specific contract shall be identical to the extent necessary to insure interchangeability of component parts, assemblies, accessories, and spare parts.

3.8 Identification Markings. Each individual plastic composite marine fender piling shall be clearly marked with the manufacturers name and distinct serial number.

3.9 Workmanship.

3.9.1 Outer Skin. The dense outer skin of the plastic composite marine fender piling shall be generally smooth but it may contain occasional blisters and pockmarks.

3.9.2 Core. The foamed inner core should be homogenous and reflect a consistent cell structure when viewed across the grain. It shall be uniform in color.

3.9.3 Reinforcing. The reinforcing elements shall be those of standard industry make and appearance, and free from kinks and sharp bends.

4. QUALITY ASSURANCE PROVISIONS

4.1 Quality Assurance. The manufacturer shall have in place a Quality Assurance Program that will insure the plastic composite marine fender piling is manufactured to the specifications noted in Sections 3.4, 3.5, 3.6, 3.9.

4.2 Examination. Each complete plastic composite marine fender pile shall be examined by an inspector of purchaser's designation for compliance with the appropriate requirements of Section 3 of this specification. This element of inspection shall encompass all visual examinations and dimensional measurements. Records maintained by the manufacturer shall be inspected to ensure that the materials used in construction of all contract items conform to the requirements stated herein. In particular, it shall be verified that the material requirements of Tables I and II, and manufacturing tolerances found in Table III are met. Noncompliance with any specified requirements or presence of one or more major defects preventing or lessening maximum efficiency shall constitute cause for rejection.

4.3 Tests. Manufacturer shall provide documentation showing that the tests described in 4.3.1 and 4.3.2 have been performed and have met the test criteria. Such tests shall be performed on a standard commercial 54 foot long pile by an independent testing laboratory supervised by a testing engineer. The manufacturer shall also provide documentation showing that the physical property tests described in Table I have been performed by an independent testing laboratory, who must certify the physical property values as noted in Table I. A copy of all test data must be available for inspection by the purchaser or his agent.

4.3.1 Bending Test. A 54 foot long plastic composite marine fender pile of manufacturer's standard commercial type shall be placed horizontally in a clamping device so that 6 feet of the piling will be firmly fixed and unable to move. The other end of the 54 foot pile shall be simply supported. A vertical (downward) load shall be gradually applied at a point 12 feet from the simply-supported end. Deflection along the length of the pile is measured at the load point, and 3 other equidistant locations. Load and deflection data shall be used to calculate the flexural modulus of elasticity and maximum outer fiber stress.

4.3.2 Crush Test. A four foot long piece of manufacturer's standard product is placed laterally on a steel plate, and a force of 500,000 lb. is gradually applied over the entire length. The sample shall show no signs of cracking or crazing.

5. ACCESSORIES

5.1 Pile Cap. The manufacturer shall provide a pile cap to be field installed following driving to permanently cover the exposed reinforcing elements and to provide a finished appearance to the driven pile. In the event the plastic composite marine piling shall be covered by a deck cap following installation, the pile cap can be eliminated.

6. SHIPPING

6.1 Shipping. The plastic composite marine fender pile shall be shipped in such a fashion as to minimize any scratching or damage to the outer surface.

7. INSTALLATION

7.1 Installation. Installation shall be in accordance with manufacturer's guidelines as noted in its owners field guide. Unless otherwise specified, installation of the plastic composite marine piling is not included as part of manufacturer's responsibility under this purchase order.

8. PURCHASING

8.1 Requirements. The following items must be included in any purchase orders:

- Length of piles
- Outer color (Black, unless otherwise specified)
- Quantity
- Required accessories
- F.O.B. point

8.2 A product meeting these specifications is manufactured by Seaward International Inc., 3470 Martinsburg Pike, Clearbrook, VA 22624 1-800-828-5360.

04/21/98

FIBERGLASS REINFORCED PLASTIC COMPOSITE MARINE FENDER PILE,

16" DIAMETER WITH SIXTEEN (16) EACH 1.25" DIAMETER FIBERGLASS REINFORCING ELEMENTS

1. SCOPE

1.1 Scope. This specification covers a fiberglass reinforced plastic composite marine fender pile to be used for protection of ships, barges, harbor craft, wharves, bridges and piers from damage between the interface of vessel to pier.

2. APPLICABLE DOCUMENTS

2.1 Publications. The following documents form a part of this specification to the extent specified herein.

ASTM D543	-	Resistance of Plastics to Chemical Reagents
ASTM D570	-	Water Absorption of Plastics
ASTM D638	-	Tensile Properties of Plastics
ASTM D695	-	Compressive Properties of Rigid Plastics
ASTM D746	-	Brittleness Temperature of Plastic and Elastomers by Impact
ASTM D792	-	Specific Gravity (Relative Density) and Density of Plastics by Displacement
ASTM D1761	-	Method of Testing Mechanical Fasteners in Wood (Section 102)
ASTM D2240		Rubber Property-Durometer Hardness

ASTM D4060	-	Abrasion Resistance of Organic Coatings by the Taber Abraser
ASTM D4329	-	Operating Light and Water Exposure Apparatus (Fluorescent UV Condensation Type) for Exposure of Plastics (UVA-340)
ASTM D4476	-	Flexural Properties of Fiber Reinforced Pultruded Plastic Rods
ASTM E12	-	Density and Specific Gravity of Solids, Liquids and Gases
ASTM F489	-	Static Coefficient of Friction

2.2 Order of precedence. In the event of a conflict between the text of this specification and the references cited herein (except for associated detail specifications or specification sheets), the text of this specification shall take precedence. Nothing in this specification, however, shall supersede applicable laws and regulations unless a specific exemption has been obtained.

2.3 Submittals. The manufacturer shall submit to the purchasing authority one (1) copy each of his standard and most recent product brochure and Technical Manual for the product covered by this specification. Copies of material test reports and performance test data wnich support compliance with the specification requirements shall be submitted to the purchasing authority as required by the procurement documents.

3. REQUIREMENTS

3.1 Standard commercial product. The fiberglass reinforced plastic composite marine fender pile shall be in accordance with the requirements of this specification and shall be the manufacturer's

standard commercial product. Additional or better features which are not specifically prohibited by this specification, but which are a part of manufacturer's standard commercial product, shall be included in the piling being furnished. A standard commercial product is a product which has been sold or is being currently offered for sale on the commercial market through advertisements or manufacturer's catalogs or brochures, and represents the latest production model. Manufacturer shall provide documentation that it has manufactured the product for a minimum of 4 years.

3.2 Drawings. The contractor is responsible for preparing his own shop drawings. Where tolerances prescribed may cumulatively result in incorrect fits, the contractor shall provide tolerances within those prescribed herein to insure correct fit, assembly, and operations of the items. No deviation from the prescribed dimensions or tolerances is permissible without prior approval of the purchaser.

3.3 Materials. Materials used shall be free from defects which would adversely affect the performance or maintainability of individual components or of the overall assembly. Materials not specified herein shall be of the same quality used for the intended purpose in commercial practice.

3.3.1 Plastic. The plastic shall be a mixture of one or more of the following recycled post consumer or post industrial thermoplastics: High density polyethylene, medium density polyethylene, low density polyethylene, and polypropylene This plastic shall be mixed with the appropriate colorants, UV inhibitors and antioxidants, so that the resulting plastic portion of the product shall conform to the characteristics as listed in Table I.

3.3.2 Reinforcing. The plastic composite marine fender pile shall be reinforced with fiberglass elements. The reinforcing elements shall conform to the characteristics found in Table II.

3.4 Design. The fiberglass reinforced plastic composite marine fender pile shall be designed as described herein.

General Configuration. The plastic composite marine fender pile shall have a round shape with both ends cut flat. It shall be seamless with a smooth outer skin.

TABLE I. PLASTIC (TYPICAL PROPERTIES)

Density (ASTM D792)	Skin	55-63 lb./cu. Ft
Density (ASTM E12)	Core/Annulus	34-50 lb./cu. Ft
Water Absorption (ASTM D570)	Skin Core/Annulus	24 hr.: < 0.5% wt. Increase 2 hr.: < 1.0% wt. Increase 24 hr.: < 3.0% wt. Increase
Brittleness (ASTM D746)	Skin	No break at -40°F
Impact Resistance (ASTM D746 modified)	Skin	Greater than 4 ft-lb./in.
Hardness (ASTM D2240)	Skin	45-55 (Shore D)
Ultraviolet (ASTM D4329 UVA-340)	Skin/Core/Annulus	No more than 10% change in Shore D durometer hardness after 500 hours exposure
Abrasion (ASTM D4060)	Skin	Weight Loss:< 0.5 g Wear Index: 2.5 to 3.0 Cycles = 10,000 Wheel = CS17 Load = 1 kg
Chemical Resistance (ASTM D543)	Skin/Core/Annulus Sea Water Gasoline No. 2 Diesel	< 1.5% weight increase < 7.5% weight increase < 6.0% weight increase
Tensile Properties (ASTM D638)	Skin/Core/Annulus	Minimum 500 psi at break
Compressive Modulus (ASTM D695)	Skin/Core/Annulus	Minimum 40,000 psi
Coefficient of Friction (ASTM F489)	Skin	Maximum 0.25, wet or dry
Nail Pull Out (ASTM D1761 Section 102)	Skin/Core/Annulus	Minimum 60 lb.

TABLE II. REINFORCING

For Fiberglass Reinforcing Elements:

Tensile Properties (ASTM D638)	Ultimate Tensile Strength	70,000 psi
Flexural Strength (ASTM D790)	Flexural Strength	70,000 psi
Compressive Properties (ASTM D695)	Compressive Strength	40,000 psi

3.4.2 Dimensions. Dimensions for the fiberglass reinforced plastic composite marine fender pile shall be as shown in Table III.

TABLE III. DIMENSIONS

Fender Pile	Dimension	Tolerance
Length	Per order (105 feet maximum)	+/-1.0 feet
Overall Diameter	16.25 inches	+/-0.250 inches
Outer Skin Thickness	3/16 inches	+/-0.125 inches
Reinforcing Element Circle Diameter (as defined by the outer edges of the reinforcing elements)	14 inches	+/-1.5 inches
Straightness (gap, bend or bulge inside while lying on a flat surface)		< 1.5 inches per 10 feet of length

3.4.3 Repairability. The outer skin must be repairable if chipped or spalled by using a commercially available plastic roofing compound.

3.5 Construction. The plastic composite marine fender piling shall be manufactured in a continuous process that will result in the piling having no joints. The plastic composite marine fender piling shall have a coextruded outer skin of dense plastic, an inner core of foamed plastic manufactured prior to the manufacture of the piling, and an annulus of foamed plastic encapsulating the reinforcing elements. The plastic composite marine fender pile shall conform to the design requirements of Section 3.4 of the specification.

3.5.1 Outer Skin. The outer skin of the plastic composite marine fender pile shall be produced so that it is continuous and homogenous throughout the entire length and circumference of the piling. It shall be formed by coextruding a plastic material at the same time that the annulus material is extruded. It shall conform to those applicable Sections of Table I, and should be black in color unless otherwise specified in the purchase documents.

3.5.2 Inner Core. The inner core of the plastic composite marine fender piling shall be a continuous foamed structure throughout the entire length of the piling. It shall conform to those applicable Sections of Table I, and shall be black in color. Butt joints as required for manufacturing may be utilized provided the full strength of the plastic is developed in the joint.

3.5.3 Annulus. The annulus of the piling shall be a continuous foamed structure throughout the entire length of the piling. It shall conform to those applicable Sections of Table I, and shall be black in color. The annulus shall be bonded to the inner core by melting the inner core, in such a manner that the joint between the inner core and the annulus develops the full strength of the plastic.

3.5.4 Reinforcing. The reinforcing elements shall be arranged in a concentric pattern, as described in Table III, within the annulus of the plastic composite marine fender piling. Each plastic composite marine fender pile shall have a quantity of sixteen (16) fiberglass reinforcing elements, 1.25" inch in diameter. Each individual element shall typically run the entire length of the piling, to within 1.0 feet from either end. No plastic, fiberglass or metal elements or supports for the reinforcing element shall be used in the piling.

3.5.5 Owners Field Guide. With the shipment of the first plastic composite marine fender pile, the manufacturer shall provide one copy of its owners field guide. This guide shall include information and diagrams describing and illustrating the recommended means for handling, placing, driving, and finishing the plastic composite marine fender pile.

3.6 Performance. The plastic composite marine fender pile shall be designed to provide the following structural characteristics when using the material properties shown in Tables I and II.

Flexural Modulus of Elasticity	>775,000 psi
Stiffness (EI)	>2.49 x 10^9 lb·in^2
Yield Stress in Bending	>6,300 psi
Weight	64-78 lb./ft.

3.7 Interchangeability. All units of the same classification furnished with similar options under a specific contract shall be identical to the extent necessary to insure interchangeability of component parts, assemblies, accessories, and spare parts.

3.8 Identification Markings. Each individual plastic composite marine fender piling shall be clearly marked with the manufacturers name and distinct serial number.

3.9 Workmanship.

3.9.1 Outer Skin. The dense outer skin of the plastic composite marine fender piling shall be generally smooth but it may contain occasional blisters and pockmarks.

3.9.2 Core. The foamed inner core should be homogenous and reflect a consistent cell structure when viewed across the grain. It shall be uniform in color.

3.9.3 Reinforcing. The reinforcing elements shall be those of standard industry make and appearance, and free from kinks and sharp bends.

4. QUALITY ASSURANCE PROVISIONS

4.1 Quality Assurance. The manufacturer shall have in place a Quality Assurance Program that will insure the plastic composite marine fender piling is manufactured to the specifications noted in Sections 3.4, 3.5, 3.6, 3.9.

4.2 Examination. Each complete plastic composite marine fender pile shall be examined by an inspector of purchaser's designation for compliance with the appropriate requirements of Section 3 of this specification. This element of inspection shall encompass all visual examinations and dimensional measurements. Records maintained by the manufacturer shall be inspected to ensure that the materials used in construction of all contract items conform to the requirements stated herein. In particular, it shall be verified that the material requirements of Tables I and II, and manufacturing tolerances found in Table III are met. Noncompliance with any specified requirements or presence of one or more major defects preventing or lessening maximum efficiency shall constitute cause for rejection.

4.3 Tests. Manufacturer shall provide documentation showing that the tests described in 4.3.1 and 4.3.2 have been performed and have met the test criteria. Such tests shall be performed on a standard commercial 54 foot long pile by an independent testing laboratory supervised by a testing engineer. The manufacturer shall also provide documentation showing that the physical property tests described in Table I have been performed by an independent testing laboratory, who must certify the physical property values as noted in Table I. A copy of all test data must be available for inspection by the purchaser or his agent.

4.3.1 Bending Test. A 54 foot long plastic composite marine fender pile of manufacturer's standard commercial type shall be placed horizontally in a clamping device so that 6 feet of the piling will be firmly fixed and unable to move. The other end of the 54 foot pile shall be simply supported. A vertical (downward) load shall be gradually applied at a point 12 feet from the simply-supported end. Deflection along the length of the pile is measured at the load point, and 3 other equidistant locations. Load and deflection data shall be used to calculate the flexural modulus of elasticity and maximum outer fiber stress.

4.3.2 Crush Test. A four foot long piece of manufacturer's standard product is placed laterally on a steel plate, and a force of 500,000 lb. is gradually applied over the entire length. The sample shall show no signs of cracking or crazing.

5. ACCESSORIES

5.1 Pile Cap. The manufacturer shall provide a pile cap to be field installed following driving to permanently cover the exposed reinforcing elements and to provide a finished appearance to the driven pile. In the event the plastic composite marine piling shall be covered by a deck cap following installation, the pile cap can be eliminated.

6. SHIPPING

6.1 Shipping. The plastic composite marine fender pile shall be shipped in such a fashion as to minimize any damage to the outer surface.

7. INSTALLATION

7.1 Installation. Installation shall be in accordance with manufacturer's guidelines as noted in its owners field guide. Unless otherwise specified, installation of the plastic composite marine piling is not included as part of manufacturer's responsibility under this purchase order.

8. PURCHASING

8.1 Requirements. The following items must be included in any purchase orders:

- Length of piles
- Outer color (Black, unless otherwise specified)
- Quantity
- Required accessories
- F.O.B. point

8.2 A product meeting these specifications is manufactured by Seaward International Inc., 3470 Martinsburg Pike, Clearbrook, VA 22624 1-800-828-5360.

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